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Kingite, a new hydrated aluminium phosphate mineral from Robertstown, South Australia.

By K. Norrish, M.Sc., Ph.D., A.Inst.P., Lillian E. R. Rogers, M.Sc., and R. E. Shapter, A.A.C.I.

Division of Soils,
Commonwealth Scientific and Industrial Research Organization,
Adelaide, South Australia.

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Summary. A new hydrated aluminium phosphate mineral, *kingite*, from phosphate workings near Robertstown, South Australia, has an idealized formula $Al_2O_3.Al(OH)_3.P_2O_5.9H_2O$, with some replacement of OH by F. The specific gravity is 2·2 to 2·3, refractive index 1·514, and percentage chemical composition Al_2O_3 31·92, P_2O_5 28·63, H_2O 37·93. The three strongest lines on the X-ray diffraction pattern are 9·1, 3·45, and 3·48 Å. Kingite changes to a less hydrated phase between 154° C. and 163° C., which is also considered to be a new aluminium phosphate (*meta-kingite*) with idealized formula $Al_2O_3.Al(OH)_3.P_2O_5.4H_2O$. The strongest lines of its X-ray diffraction pattern are at 7·4, 5·02, and 3·19 Å.

DURING an investigation of phosphate minerals in connexion with soil phosphate studies being carried out by us, Mr. D. King, Geologist, of the Department of Mines, South Australia, obtained for us phosphate rocks from various localities. A sample from the Fairview phosphate workings, Robertstown, South Australia, especially noted by Mr. King, proved to be a new hydrated aluminium phosphate mineral. It has been named kingite.

Occurrence. The mineral occurs in a fairly pure state as nodules in the phosphate deposits near Robertstown (central province, section 225, hundred of Bright, county Burra, 13 miles north of Robertstown and 20 miles east of Burra). The nodules are white and may be up to 2 inches in diameter; when removed they are coated with a brown powder which

also runs through the nodules in very thin veins. Specimens of the mineral can easily be prepared free from the brown powder and these are found to be pure kingite except for a trace of sodium chloride. X-ray powder diffraction analysis shows that the brown powder is talc, quartz, and sodium chloride, with possibly a little gypsum and hematite or goethite or both. The phosphate deposits near Robertstown are described in a paper by D. King and W. H. Knapman[1] who state that other phosphates present have been identified as vivianite, fluorapatite (collophane), and leucophosphite. The phosphates are associated with Cambrian and Upper Precambrian limestones. They are probably of supergene origin and have been deposited from meteoric waters in fault zones and breccias during Tertiary times. T. W. E. David[2] states that 'in close proximity to the lime phosphates there are deposits of hydrous aluminium phosphates due, apparently, to replacements of slates and shales'.

Since the completion of the work on the original specimen, Mr. D. King has found another deposit of kingite, occurring in the same nodular form in Precambrian sediments at the same stratigraphic level as the original deposit (Torrensian series of dolomites and magnesites). The deposit occurs in an old ironstone quarry near the Clinton phosphate workings, in the hundred of Clinton, section 350, and is about 64 miles west-south-west of the first deposit. The diffraction patterns of kingite from the two localities were identical, except that the Clinton sample showed a trace of goethite.

Physical, chemical, and X-ray diffraction data. The nodules are composed of a soft white powder that is too fine-grained for detailed microscopic examination. The mean refractive index is 1·514. The density was determined on lumps and on powdered material; although the pycnometers were evacuated to remove entrapped air, the results were variable, presumably due to the fine porous nature of the material. The following values for specific gravity were obtained: 2·21, 2·30, 2·30.

Weight loss and changes in the X-ray powder diffraction pattern on heating were studied. The weight-loss curve is shown in fig. 1. The mineral loses 10 % of its oven-dry (98° C.) weight at 120° C. and a new phase (meta-kingite) begins to appear. At 160° C., with a weight loss of 20 %, the formation of the second phase appears to be complete, and this decomposes to give an amorphous phase. The cristobalite form of $AlPO_4$ begins to form at 410° C. and its crystallization continues with a

[1] Mining Review, Dept. of Mines, South Australia, 1956, no. 99, p. 25.

[2] The Geology of the Commonwealth of Australia, London, 1950, vol. 1, p. 350.

gradual loss of water until the only phases present are $AlPO_4$ and a little corundum. The ignition products are $AlPO_4$ (cristobalite form) and corundum.

The results of the chemical analysis of kingite are given in table I. A

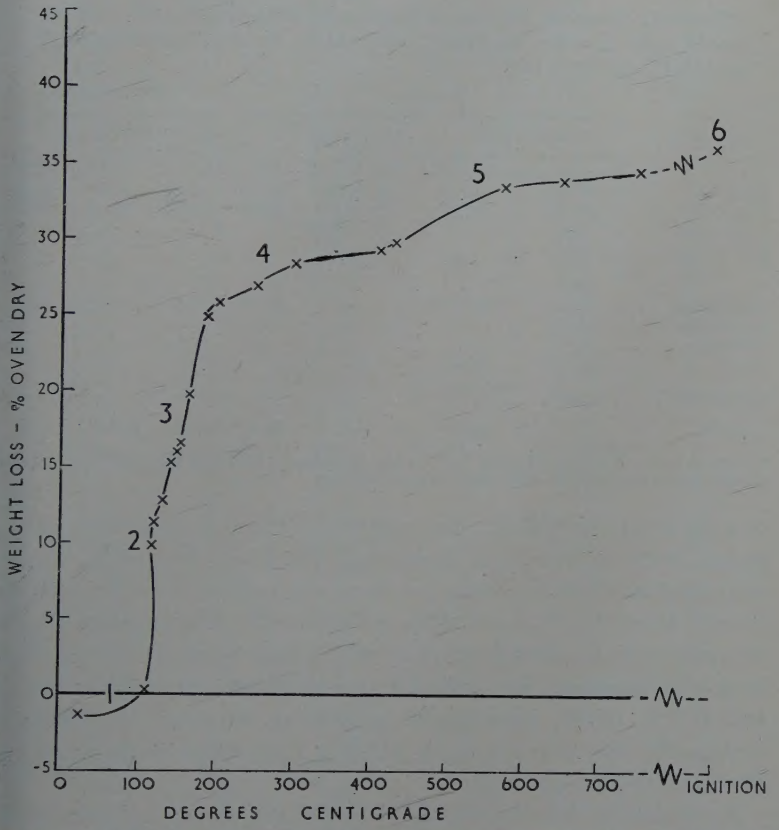

FIG. 1. Weight-loss of kingite with temperature. X-ray photographs show that the phases present in the several regions are: 1, kingite. 2, kingite + meta-kingite. 3, meta-kingite. 4, amorphous. 5, amorphous + $AlPO_4$. 6, $AlPO_4 + Al_2O_3$.

trace of chlorine was found and it has been associated with the small amount of sodium, as sodium chloride is a known trace contaminant. (Sodium chloride was recognized in the X-ray diffraction powder photographs by the spotty nature of its lines and also from the persistence of these lines in the diffraction pattern of the material after it had been heated to 200° C.) As part of the water loss at 110° C. may be structural

water, for the purpose of calculating the chemical formulae H_2O- has been taken as the loss at 98° C. Calculated from the data in table I, the idealized formula of kingite is $Al_2O_3.Al(OH)_3.P_2O_5.9H_2O$, with some replacement of OH by fluorine. The calculation of the exact formula

TABLE I. Chemical analyses of kingite and meta-kingite. The columns headed Calc. give the theoretical compositions for $Al_3(PO_4)_2(OH)_3.9H_2O$ and $Al_3(PO_4)_2(OH)_3.4H_2O$.

	Kingite.				Meta-kingite.		
	% composition.		Atomic ratio to basis P = 2.	Calc.	% composition.		
	Experimental.	Corrected.*			154° C.	163° C.	Calc.
Al_2O_3	31·92	32·25	Al = 3·10	32·10	38·67	40·23	38·81
P_2O_5	28·63	28·93	P = 2	29·83	35·05	36·46	36·03
Na_2O	0·47	—	H = 20·85	—	—	—	—
K_2O	0·01	—	O = 20·18	—	—	—	—
F	0·84	0·85	—	—	—	—	—
Cl	trace	—	—	—	—	—	—
Loss on Ign.	36·52	38·32(H_2O+)	—	38·07	26·29	23·30	25·15
Loss at 110° C.	2·71	—	—	—	—	—	—
Insoluble	0·02	—	—	—	—	—	—
Total	101·12	100·35	—	—	—	—	—
Loss at 98° C.	1·3	Less O for F 0·35	—	—	—	—	—
Total		100·0	—	100·0	100·0	100·0	100·0

* Loss at 98° C. has been taken as H_2O-; and as sodium chloride is a known contaminant, sodium has been associated with chlorine and deducted.

of meta-kingite is difficult; the weight loss curve is very steep in this region, and it is difficult to decide from the X-ray data when, if ever, meta-kingite alone is present as there are resemblances between its powder diffraction data and those of kingite. In addition, meta-kingite decomposes to an amorphous phase which only becomes obvious when large amounts are present. Calculating from the water content at 154° C. and 163° C. (where meta-kingite appears to be pure), the idealized formula for this phase is $Al_2O_3.Al(OH)_3.P_2O_5.nH_2O$ where n lies between 3·5 and 4·5 (see table I).

X-ray powder diffraction data for kingite and meta-kingite are given in table II. The powder diffraction photographs for kingite, meta-kingite, wavellite, and wardite are shown in fig. 2. Attempts were made to index the diffraction photograph of kingite but the symmetry proved too low or the unit cell too large to allow indices to be assigned. The mineral does not appear to have cubic, tetragonal, or hexagonal symmetry.

Differential thermal analysis. A differential thermal analysis was carried out by Mr. R. M. Taylor, at a heating rate of 10° C. per minute, against a standard of aluminium oxide, and gave the curve shown in

TABLE II. X-ray powder diffraction data for kingite and meta-kingite. Co-$K\alpha$ radiation, λ 1·7889 Å.

Kingite.*				Meta-kingite.†	
d Å.	*I.*	*d* Å.	*I.*	*d* Å.	*I.*
9·8	9	2·476	7	9·8	40
9·1	100	2·446	5	7·4	100
7·2	6	2·404	1	6·84	60
6·85	24	2·365	1	6·30	30
6·27	14	2·336	5	5·71	30
5·34	28	2·300	7	5·41	30
5·28	52	2·292	2	5·02	90
5·10	24	2·274	2	4·79	60
4·96	4	2·269	3	4·66	60
4·86	5	2·255	1	4·13	20
4·61	18	2·248	3	3·76	20
4·55	5	2·233	7	3·59	60
4·36	8	2·216	4	3·42	30
3·93	15	2·208	4	3·35	20
3·75	1	2·196	3	3·19	80
3·60	6	2·189	1	3·100	60
3·48	65	2·182	1	3·012	60
3·45	80	2·159	2	2·962	60
3·38	27	2·148	2	2·883	10
3·29	2	2·127	3	2·793	10
3·24	2	2·112	14	2·696	50
3·17	39	2·054	3	2·656	20
3·14	15	2·041	1	2·569	5
3·108	30	2·026	6	2·470	20
3·066	14	2·005	2	2·355	20
3·018	10	1·990	8	2·282	50
2·975	24	1·974	13	2·209	50
2·940	4	1·922	3	2·122	20
2·893	2	1·914	1	2·002	20
2·846	9	1·900	5	1·887	20
2·837	6	1·882	1	1·854	5
2·759	7	1·875	1	1·808	20
2·712	3	1·858	3	—	—
2·667	2	1·835	13	—	—
2·640	12	1·814	1	—	—
2·617	9	1·805	3	—	—
2·590	5	1·788	2	—	—
2·568	8	1·772	4	—	—
2·551	4	—	—	—	—
2·529	3	—	—	—	—

Data for kingite obtained with a Philips high-angle diffractometer; intensities given are based on relative peak heights. Data for meta-kingite obtained with 5·73 cm. diameter camera and intensities estimated by eye. Both patterns extend considerably beyond the spacings given but as the lines are very numerous and weak accurate measurement of individual lines becomes difficult.

* Kingite, Fairview Mine, Robertstown, South Australia. The pattern remains unchanged to 120° C.

† Kingite heated to 163° C.

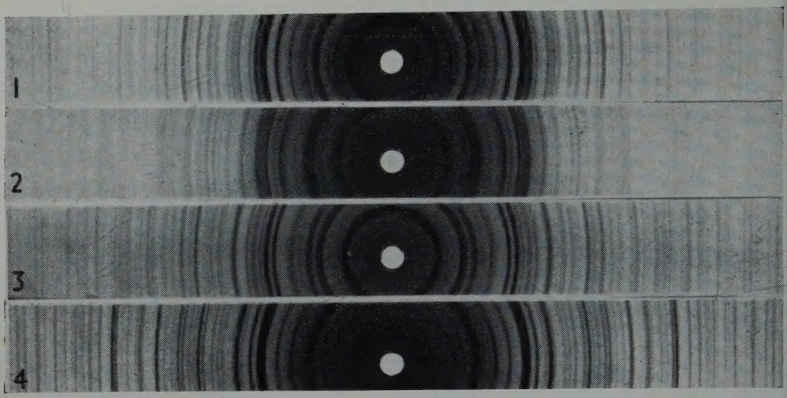

FIG. 2. Powder diffraction photographs, taken with Co-$K\alpha$ radiation in a 5·73 cm.-diameter camera; reduced 4:4·7. 1. Kingite, Fairview Mine, Robertstown, South Australia. 2. Meta-kingite. 3. Wavellite, York County, Pennsylvania, U.S.A. 4. Wardite, Fairfield, Utah, U.S.A.

fig. 3. The low-temperature endothermic peak corresponding to the phase changes kingite → meta-kingite → amorphous material shows evidence of being resolved. The broad exothermic reaction (600–700° C.) confirms that the recrystallization of the amorphous material is gradual.

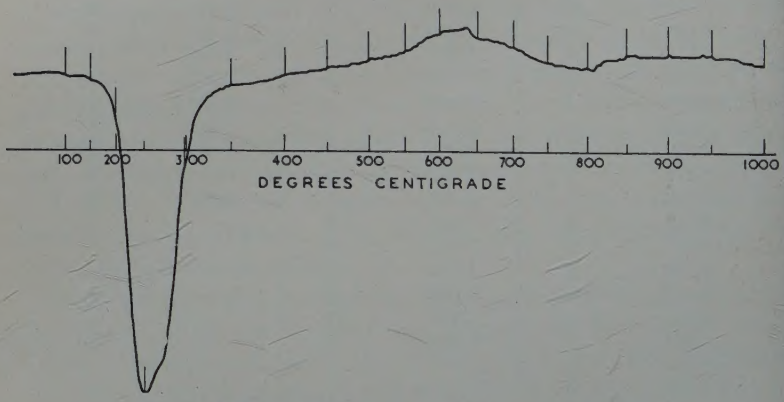

FIG. 3. Differential thermal analysis curve for kingite.

Discussion. Initially it was suspected that kingite could have been a mixture containing wardite, but its behaviour on heating and a comparison of its X-ray diffraction data with that of wardite shows that this is not so, although the two minerals have some lines in common.

Other aluminium phosphate minerals with the same Al_2O_3 to P_2O_5 ratio as kingite are less hydrated (e.g. sterrettite and wavellite) and give different diffraction data. A comparison of the diffraction patterns of meta-kingite and wavellite, fig. 2, shows them to be different structurally, if not chemically. X-ray diffraction and chemical analyses indicate that both kingite and meta-kingite are new hydrated aluminium phosphate compounds.

Acknowledgements. The authors wish to thank Dr. C. Frondel for supplying a specimen of wardite and for critically reading the manuscript.

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The normal-pattern finder: an aid to stereographic projection.

By G. Boom.

Kristallografisch Instituut, Groningen University,
The Netherlands.

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Summary. The normal-pattern finder is a mechanical aid for use in finding the various possible configurations of a construction in the Barker system for anorthic crystals. Its purpose is to avoid the drawing of zones in pencil on the stereographic projection, which zones make it more difficult to recognize other differently constructed normal-patterns.

THE instrument here described was devised as an aid in the application of the Barker method of determinative crystallography to anorthic crystals, but is also useful in a variety of optical and other problems handled in stereographic projection.

A fundamental step in the Barker system is to seek out all ways in which as many as possible of the observed faces can be assigned 'simple' indices, defined as indices including only the numbers 0, $+1$, and -1; the thirteen possible pairs of parallel faces with simple indices lie at the intersections of the nine zones [100], [010], [001], [110], [$1\bar{1}0$], [101], [$\bar{1}01$], [011], and [$0\bar{1}1$], which map out a 'normal pattern'. The normal-pattern finder is primarily a device for testing whether any given group of poles in a stereographic projection can be located in a normal pattern, and avoids drawing large numbers of zone-circles (which may be an obstacle in recognizing a different normal pattern, involving a different selection of poles).

The instrument consists of an assembly of two metal rings (*a* and *b*), held together by three small metal plates (*c*) so as to form a slot through which the six screws (*d*) can slide. These screws (*d*) clamp the sliders (*e*) by means of the milled nuts (*f*).

The sliders each carry four wire-holders (*g*) and a clamping mechanism for these. Through each of the wire-holders is bored a small horizontal hole through the three lowest of which are passed steel wires of 0·3 mm. diameter. Each wire can be clamped firmly under the wire-holder that lies immediately above it by turning the screw (*h*). The wire-holders are also provided with a hole of 2 mm. diameter bored through in a vertical

direction. When the screw (*h*) is loose the holders can be turned freely on one another.

There are three pairs of sliders (*e*), each pair consisting of one long and one short. In the case of the short sliders the wires are pushed through

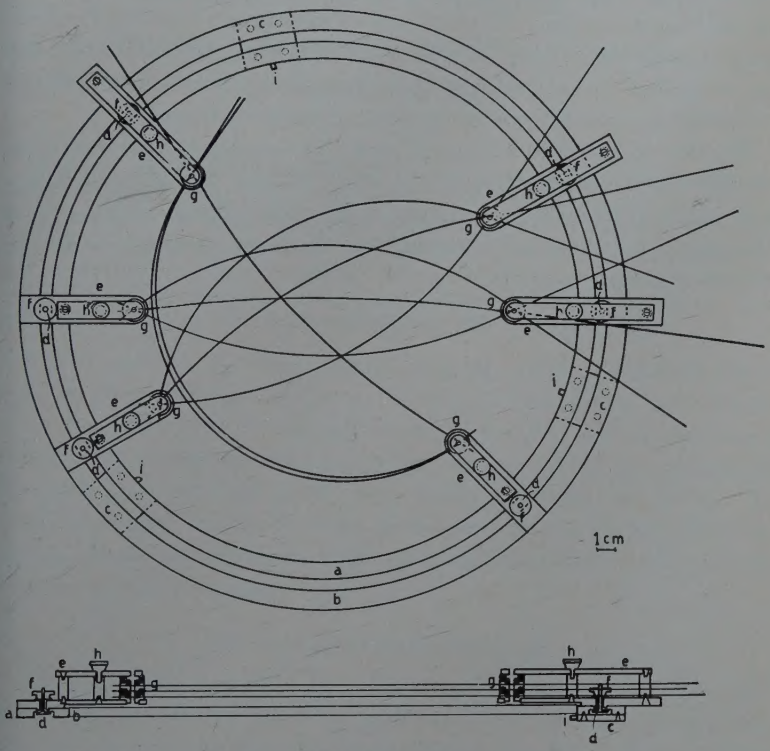


FIG. 1. The normal-pattern finder.

without any overlapping ends; with the long ones the wires are allowed to protrude. The wires should be of such a length that when bent into the form of a semicircle between the sliders they protrude about 4 cm. through the longer slides.

The whole instrument can be laid on a stereographic net (e.g. such as that supplied by Leitz) in such a way that the pegs (*i*) engage with slots formed in the movable outer ring of the net.

If two of the sliders (one pair) are now placed above two diametrically opposite face-poles on the base circle (these poles may be observed through the holes bored in (*g*)) the steel wires can be given the form of

great circles in the stereographic projection merely by pushing the wire in or out of (g) and turning (g). With the aid of the three sets of sliders (9 wires in all) all the different possible normal-patterns may be formed.

Thus, given a number of face-poles, the various possible configurations can be sought by means of this instrument, the projection remaining all the time unmarked. Without such an instrument it is usually necessary to mark the various zones in pencil before the normal-pattern can be recognized; the existence of these lines then makes it more difficult to recognize other differently constructed normal-patterns.

In order to ascertain whether a given face-pole in the projection coincides with an intersection of the wires, a small half-silvered mirror may be used; by making the image of the wires coincide with the wires themselves it is possible to ensure that readings are made in a truly vertical position.

A further investigation of tobermorite from Loch Eynort, Scotland.

By J. A. Gard, B.Sc., and H. F. W. Taylor, B.Sc., Ph.D.

Department of Chemistry, University of Aberdeen.

[Read 7 June 1956.]

Summary. The specimen described by Claringbull and Hey (1952) has been re-examined using electron-microscope, electron-diffraction, X-ray, and dehydration isobar methods. It differs from other specimens in several respects. The basal spacing does not shrink appreciably on dehydration. The principal cleavage is (100) and not (001). The body-centred pseudo-cell is of normal dimensions, but the distribution of the weak reflections differs from that found for other specimens. The mechanism of conversion into wollastonite has also been examined.

THE specimen of tobermorite ($Ca_5Si_6O_{18}H_2.4H_2O$; McConnell, 1954) to which this paper relates was discovered by Heddle (1893). It has since been examined by Claringbull and Hey (1952) and by McConnell (1954). The present examination, which was carried out on a portion of analysed material (BM. 1937,1490) kindly provided by Dr. G. F. Claringbull and Dr. M. H. Hey, shows that this specimen differs in several respects from tobermorite specimens from some other localities, or made in the laboratory.

Electron-microscope investigation.

Each of the specimens described in this section was prepared by crushing a small quantity of the material in water, and allowing a drop of the diluted suspension to dry on a specimen grid coated with formvar film. Electron micrographs (fig. 1), obtained using a Metropolitan-Vickers type EM3 electron microscope, show that the material splits into fibrous or acicular crystals. The ones examined were mostly about 5μ long and 2μ broad, and their thickness was found by shadow-casting (Williams and Wyckoff, 1944) to be somewhat less than their breadth. Electron-diffraction patterns were obtained from about one hundred individual crystals. In all but three cases substantially identical patterns were obtained (fig. 2). Measurement of these patterns, and comparison of the resulting data with the known unit-cell parameters of tobermorite (McConnell, 1954), showed that the crystals yielding them were lying on (100) and that they were elongated parallel to *b*. Some of the crystals

(fig. 1, inset) lying on (100) exhibited multiple dark fringes similar to those observed in graphite by Mitsuishi, Nagasaki, and Uyeda (1951)

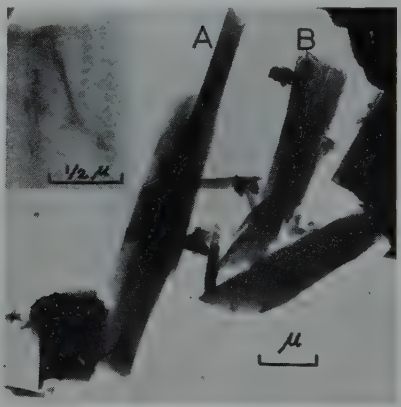
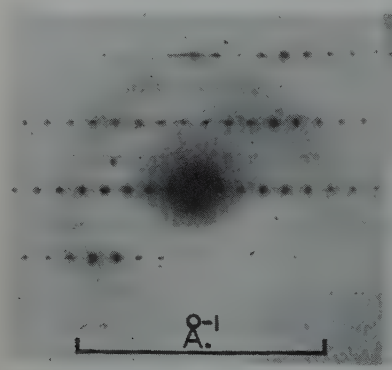


Fig. 1. Electron micrograph of tobermorite from Loch Eynort, showing crystals lying on (100) (A) and on (001) (B). *Inset*: crystal lying on (100) showing multiple dark fringes (see text).



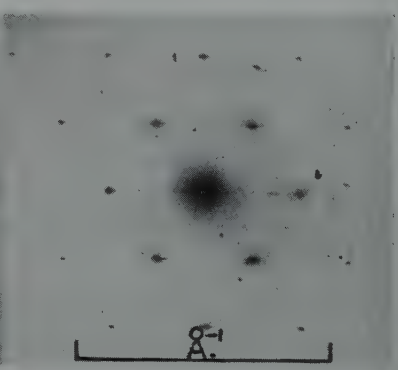


Fig. 2. Fig. 3.

Fig. 2. Electron-diffraction pattern of tobermorite from Loch Eynort; (100) normal to the electron beam. b^* vertical.

Fig. 3. Electron-diffraction pattern of tobermorite from Loch Eynort; (001) normal to the electron beam. b^* vertical.

and in mica by Rang (1953). They are commonly observed in electron micrographs of layer-lattice specimens, and are believed to be due to interference of electron waves reflected successively from lattice planes of two lamellae that are in slightly different orientations. Their occur-

rence in the tobermorite crystals confirms the good (100) cleavage. Three crystals only were found that were lying on (001). In appearance (fig. 1) they do not differ significantly from those lying on (100); the diffraction pattern given by one of them is shown in fig. 3.

The diffraction patterns for both orientations contain systematically

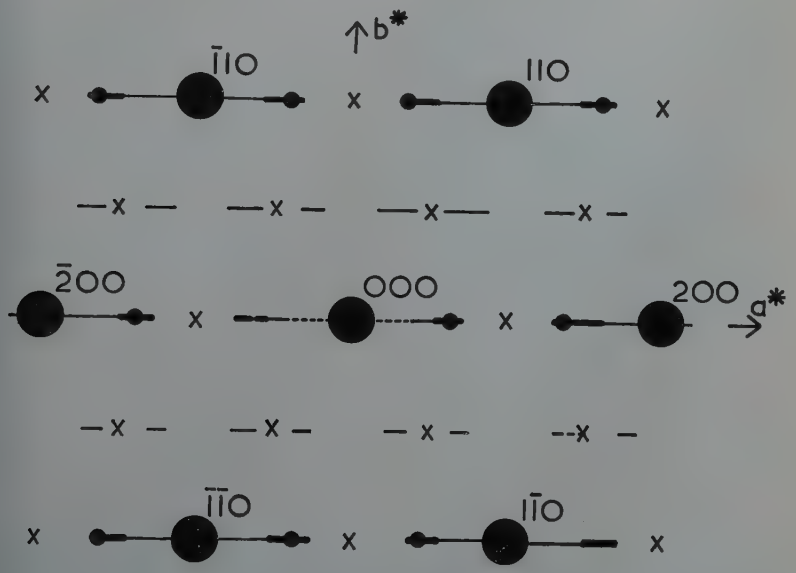


FIG. 4. Superimposed electron-diffraction patterns of tobermorite from Loch Eynort and made in the laboratory; drawing traced from enlargements of patterns given by crystals having (001) normal to the electron beam. Large full circles: strong reflections, given by both specimens, with indices in terms of the pseudo-cell (a 5·6, b 3·66 Å.). Small full circles and lines: weak reflections given by the specimen from Loch Eynort. Crosses: weak reflections given by the synthetic specimen.

strong and systematically weak groups of reflections. From measurements of the strong reflections the pseudo-cell was found to be body-centred with a 5·48±0·12, b 3·66±0·07, c 22·5±0·1 Å., $\alpha = \gamma = 90°$. The value of a was derived from the patterns given by the three crystals lying on (001). β could not be determined from the electron-diffraction patterns. Rather large variations were observed between individual crystals, and were probably outside experimental error.

The patterns given both by crystals lying on (100) and by those lying on (001) show strong pseudo-halving of b, so that the true value of b is twice that for the pseudo-cell. The true value of a is uncertain. The pattern given by crystals lying on (001) is shown in more detail in fig. 4,

with the strong reflections indexed in terms of the pseudo-cell. The weak reflections fall into two groups, characterized by odd and even true values of k. The reflections of both groups appear to have non-integral h-indices. All are elongated to some extent along a^*, and where true k is even, each of the strong reflections has two associated weaker spots joined to it by streaks. In order to obtain information concerning weak reflections not in the $0a^*b^*$ section of the reciprocal lattice shown in figs. 3 and 4, patterns were obtained from crystals tilted a few degrees from the position with (100) normal to the beam. In these patterns (fig. 5), Laue zones can be distinguished that correspond to different sections of the reciprocal lattice normal to a^*. The zones with h equal to 1, 0, and $\bar{1}$ (in terms of the pseudo-cell) are indicated in fig. 5. Between them lie various zones of weak reflections. Examination of these intermediate zones showed that the weak reflections with true k odd are elongated into streaks, parallel to c^*, with only diffuse maxima. The weak reflections with true k even are only slightly elongated parallel to c^*. Their positions along c^* are not very clear, but suggest that their distribution relative to the strong spots is the same within each layer of the reciprocal lattice normal to c^* as that shown for the zero layer in fig. 4. An impression of the reciprocal lattice thus obtained is given in fig. 6*a*.

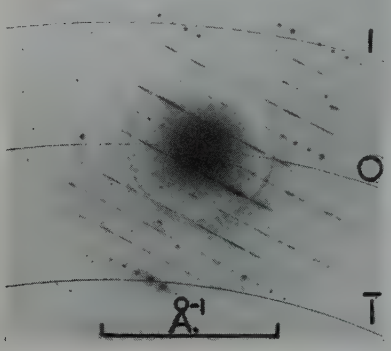


FIG. 5. Electron-diffraction pattern of tobermorite from Loch Eynort; (100) tilted a few degrees from the plane normal to the electron beam. Approximate positions of Laue zones corresponding to $h = 1$, $h = 0$, and $h = \bar{1}$ are indicated.

For comparison, electron micrographs and diffraction patterns were obtained of a typical synthetic tobermorite which had been prepared hydrothermally at 140° C. The specimen,[1] which had the approximate composition $CaO.SiO_2.H_2O$, was closely similar to the one for which X-ray powder data were quoted by Claringbull and Hey (1952). The electron micrographs (fig. 7) showed it to consist of thin foils with no marked elongation in any direction. Electron-diffraction patterns (fig. 8) given by these showed that the sheets were in all cases parallel to

[1] Specimen 67 of Heller and Taylor (1951).

(001). The strong reflections were identical with those given by the Loch Eynort specimen in the same orientation, but the weak reflections differed, and their positions are shown in fig. 4. An impression of the reciprocal lattice for the synthetic material is given in fig. 6*b*.

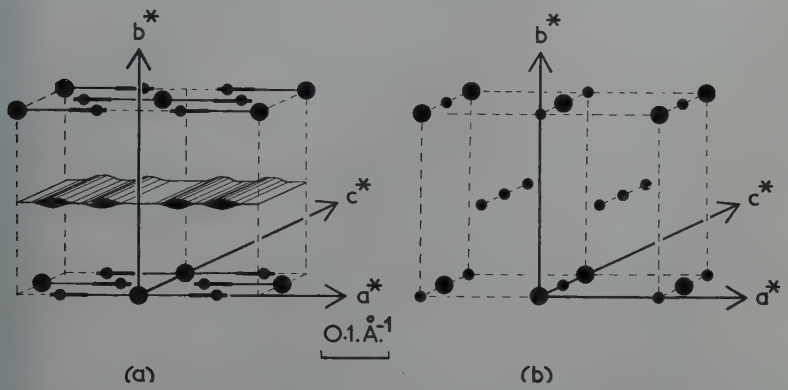


Fig. 6. Three-dimensional impression of the reciprocal lattices for tobermorite, (*a*) from Loch Eynort, and (*b*) made synthetically, illustrating the more complex distribution of the superlattice reflections in (*a*) and their elongations in the a^* and c^* directions. The discontinuous lines merely indicate the outlines of the reciprocal pseudo-cells. Space-group absences are omitted.

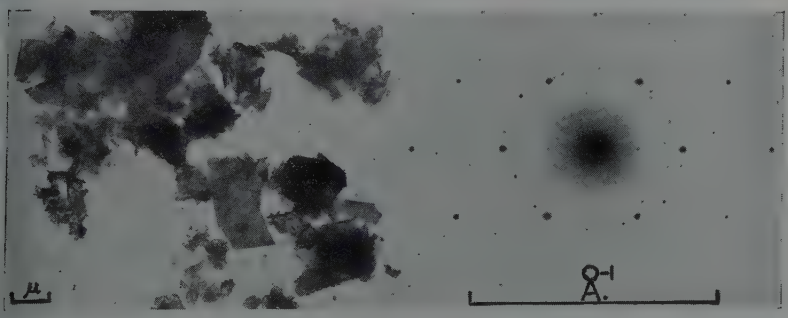


Fig. 7. Fig. 8.

Fig. 7. Electron micrograph of synthetic tobermorite made hydrothermally at 140° C.

Fig. 8. Electron-diffraction pattern of synthetic tobermorite; (001) normal to the electron beam, b^* of the principal crystal vertical.

X-ray investigation.

The Loch Eynort specimen contained no crystals of sufficient size for single-crystal X-ray work. A powder photograph was obtained using a

6-cm. diameter camera with filtered copper radiation. The results (fig. 9, line 1) agreed closely with those of Claringbull and Hey (1952). The

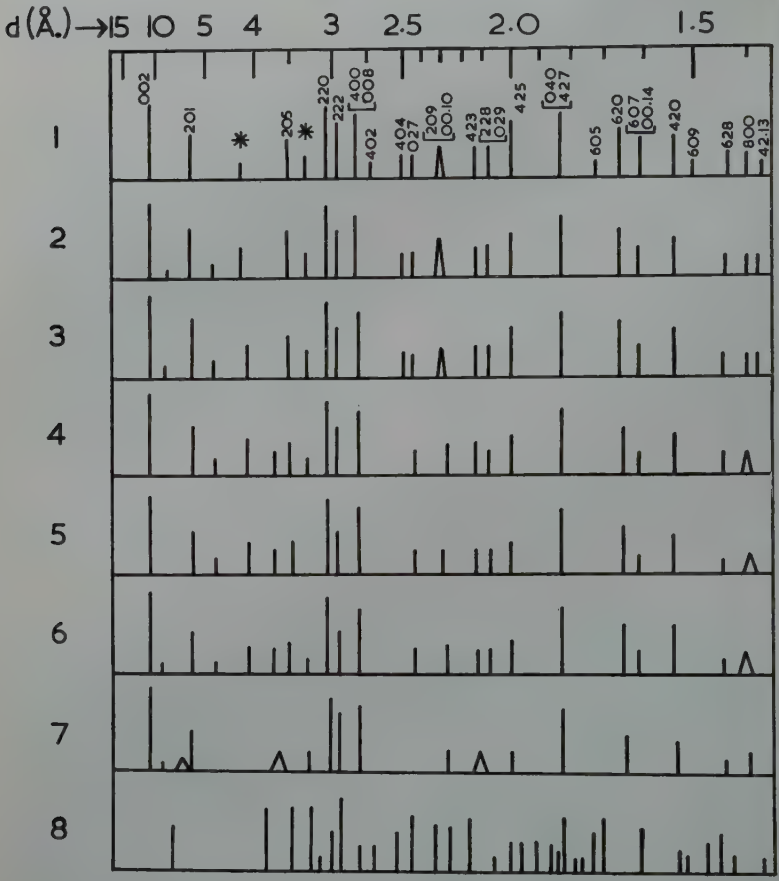


Fig. 9. X-ray powder data for tobermorite from Loch Eynort, in its natural state and after heating. (1) Unheated; also after 24 hours at 110° C., 24 hours at 200° C., or 24 hours at 290° C. (patterns virtually identical); for basis of indexing, see text. (2) 24 hours at 295° C. (3) 24 hours at 390° C. (4) 56 hours at 525° C. (5) 14 days at 550° C. (6) 24 hours at 625° C. (7) 24 hours at 750° C. (8) 96 hours at 900° C.

reflections were indexed by direct comparison of the powder photograph with single-crystal photographs of a specimen of tobermorite from Ballycraigy, kindly provided by Dr. J. D. C. McConnell. The pseudo-cell dimensions for the Loch Eynort specimen were thus found to be a 5·60, b 3·67, c 22·6 Å., $\alpha = \beta = \gamma = 90°$, in agreement with the

electron-diffraction result. All the powder spacings, except two weak ones (marked * in fig. 9), can be attributed to the strong reflections indexable in terms of the pseudo-cell. The indices given in fig. 9 relate to a cell with a 2×5·60, b 2×3·67, c 22·6 Å., $\alpha = \beta = \gamma = 90°$, which is similar to the true cell for the Ballycraigy specimen.

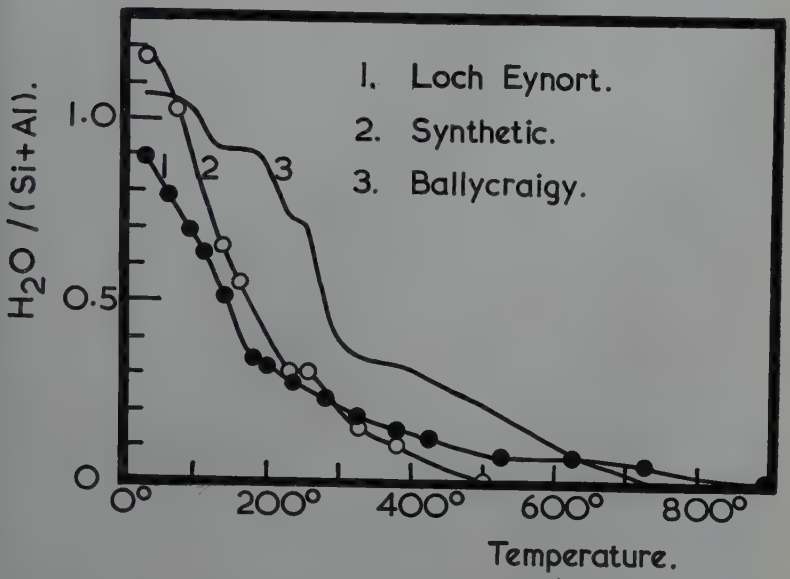


FIG. 10. Dehydration curves for tobermorite. (1) specimen from Loch Eynort; isobar determined at p(H_2O) = 6 mm. (2) synthetic preparation; isobar determined at p(H_2O) = 6 mm. (3) specimen from Ballycraigy; recalculated from data given by J. D. C. McConnell (1954).

Dehydration.

Dehydration isobars (fig. 10)[1] were determined at 6 mm. pressure of water vapour for the Loch Eynort specimen and for the synthetic preparation used in the electron-microscope investigation. The method has been described previously (Taylor, 1953). A dehydration curve for tobermorite from Ballycraigy (from McConnell, 1954) is also included in fig. 10.

Separate portions of the Loch Eynort specimen were heated to various temperatures and X-ray powder photographs then taken. The temperature, duration of heating, and results of each experiment are given in

[1] Plotted as $H_2O/(Si+Al)$ on the assumption that Al in the Loch Eynort specimen replaces Si; values of H_2O/Si would for this specimen be 10·9 % higher. Neither the Ballycraigy specimen nor the synthetic one contained appreciable alumina.

fig. 9. Except for the experiments at 550°, 750°, and 900° C., heating was done in an atmosphere containing 6 mm. partial pressure of water vapour and virtually free from carbon dioxide.

Specimens heated for 14 days at 550° C. or for a few hours at 1000° C. were examined using the electron microscope. The one heated at 550° C. showed no significant changes either in appearance or in the diffraction pattern given by crystals lying on (100). The one heated at 1000° C. consisted of pseudomorphs of the original material. These gave a diffraction pattern which resembled those of the original material in showing strong and weak layer-lines corresponding to a true repeat distance of about 7·3 Å. along the fibre direction. The even layers showed an irregular distribution of reflections, which could possibly have been caused by the presence of a number of crystallites rotated at random around the fibre direction. The odd layers were streaks.

Discussion.

The present results show that tobermorite from Loch Eynort has substantially the same pseudo-cell as that from Ballycraigy. The X-ray powder photographs are also closely similar (McConnell, 1954). The essential structure of the Loch Eynort material is therefore almost certainly the same as that established for the Ballycraigy specimen by Megaw and Kelsey (1956 *a* and *b*). At the same time, the Loch Eynort specimen differs from the Ballycraigy one, and also from synthetic and certain other natural specimens in three respects:

The principal cleavage for the Loch Eynort specimen is (100), and (001) is secondary; in tobermorite from Ballycraigy, and in synthetic preparations, (001) is a perfect cleavage and (100) is secondary.

The basal or 002 spacing is virtually unaffected by heating, even after 14 days at 550° C. or 24 hours at 750° C. (fig. 9). A barely detectable spacing at 9·5 Å. sometimes occurs after heating at 295° C. or above, and may indicate a small degree of conversion into a state with a shorter *c*-axis, but the effect is very slight. This behaviour contrasts strongly with that of tobermorite occurring in intergrowths at Crestmore, California, or that made in the laboratory (Taylor, 1953), or that from Ballycraigy (McConnell, 1954), all of which show reduction of the basal spacing to 9·3 -9·6 Å. after a few hours' heating at 300° C. The dehydration isobar for the Loch Eynort specimen, unlike the X-ray results, is not markedly anomalous (fig. 10), and the mineral must therefore be able to retain its original value of *c* when dehydrated to an extent which in other specimens causes a reduction. The X-ray pattern of the Loch

Eynort material is in general little affected by heating up to 750° C.; the principal effect is a relative weakening of reflections other than those with 002 and *hk*0 indices, indicating a certain disordering of the structure. This is most pronounced after heating at 750° C.

Thirdly, the spacial distribution of the reciprocal lattice points corresponding to the weak reflections is complex, and differs from that shown by the synthetic preparation (fig. 4). The electron-diffraction results obtained for the latter preparation are compatible with the view that it has the same true unit-cell (*C*-centred orthogonal with *a* 11·2, *b* 7·3, *c* 22·5 Å. approx.) as the specimen from Ballycraigy. The complex pattern of weak reflections given by the Loch Eynort specimen has not yet been interpreted. It may indicate that the true cell is different from and presumably larger than that of the Ballycraigy specimen. Alternatively, it may be more correct to regard the non-integral distribution of the weak reflections as a splitting caused by disorder, similar to that observed with plagioclase felspars (Cole, Sörum, and Taylor, 1951; Gay, 1956).[1] Disorder of a complex type undoubtedly exists in the Loch Eynort specimen, because the weak reflections are elongated in two ways, parallel to c^* and parallel to a^*. This may be correlated with the fact that (100) and (001) are both quite good planes of cleavage. Tobermorite specimens from Ballycraigy and from Scawt Hill (McConnell, 1954; Megaw and Kelsey, 1956 *a* and *b*) show streaking of weak reflections in only one direction, parallel to c^*, and have one predominant cleavage parallel to (001).

These peculiarities of the Loch Eynort specimen may be considered in the light of the structure determination by Megaw and Kelsey (1956 *a* and *b*), who confirmed that tobermorite from Ballycraigy has a layer structure, in some respects similar to those of clay minerals such as vermiculite; the layers are parallel to (001). The present results show that, in the Loch Eynort specimen, the cohesive forces between the layers are unusually strong, and that they are, in fact, stronger than those operating in the *a*-direction within the layers themselves.

The stability of the 11·3 Å. basal spacing in tobermorite from Loch Eynort has previously been noted by McConnell (1954). He found that the basal spacing of tobermorite from Loch Eynort was unaffected by grinding with water, whereas that of tobermorite from Ballycraigy readily increased to 14·6 Å. under similar conditions. He suggested that the stability of the basal spacing in the Loch Eynort specimen might be

[1] Our thanks are due to Dr. H. D. Megaw for drawing our attention to this possibility.

caused by the presence of alkali ions in interlayer positions (Claringbull and Hey, 1952, found Na_2O 0·56 %, K_2O 0·25 %). McConnell also observed appreciable variations in the mean refractive index and opacity of individual crystals of the Loch Eynort specimen, and suggested that these variations might be caused by differences in water content. The present results show that the specimen is probably inhomogeneous also as regards unit-cell dimensions, though whether these variations are associated with differences in water content or with the degree of imperfection in the structure is not established.

The X-ray powder pattern obtained after heating at 900° C. (fig. 9, line 8) is that of α-$CaSiO_3$ (wollastonite or parawollastonite). The electron-diffraction pattern obtained after heating at 1000° C. shows that orientation is preserved in the fibre direction. This can be explained by the fact that tobermorite (Megaw and Kelsey, 1956 *a* and *b*) and wollastonite (Dornberger-Schiff, Liebau, and Thilo, 1954 and 1955; Buerger, 1956; Tolliday, 1956) both contain metasilicate chains of a similar type running in this direction. To what extent orientation is preserved in the sense of rotation around this axis is uncertain; the present results suggest that considerable disorientation probably occurs in the case of the Loch Eynort material; with tobermorite from Ballycraigy, on the other hand, experiments now in progress indicate that orientation is probably almost completely preserved during this transformation.

References.

Buerger (M. J.), 1956. Proc. Nat. Acad. Sci., new ser., vol. 42, p. 113.
Claringbull (G. F.) and Hey (M. H.), 1952. Min. Mag., vol. 29, p. 960.
Cole (W. F.), Sörum (H.), and Taylor (W. H.), 1951. Acta Cryst., vol. 4, p. 20 [M.A. **11**–427].
Dornberger-Schiff (K.), Liebau (F.), and Thilo (E.), 1954. Naturwiss., vol. 41, p. 551.
—— 1955. Acta Cryst., vol. 8, p. 752.
Gay (P.), 1956. Min. Mag., vol. 31, p. 21.
Heddle (M. F.), 1893. Trans. Geol. Soc. Glasgow, vol. 9, p. 254.
Heller (L.) and Taylor (H. F. W.), 1951. Journ. Chem. Soc., p. 2397 [M.A. **11**–471].
McConnell (J. D. C.), 1954. Min. Mag., vol. 30, p. 293.
Megaw (H. D.) and Kelsey (C. H.), 1956*a*. Nature, vol. 177, p. 390.
—— 1956*b*. Symp. Int. Union Crystallography, Madrid, 1956.
Mitsuishi (T.), Nagasaki (H.), and Uyeda (R.), 1951. Proc. Japan Acad., vol. 27, p. 86.
Rang (O.), 1953. Zeits. Physik, vol. 136, p. 465.
Taylor (H. F. W.), 1953. Journ. Chem. Soc., p. 163 [M.A. **12**–172].
Tolliday (J.), 1956. Private communication.
Williams (R. E.) and Wyckoff (R. W. G.), 1944. Journ. Appl. Physics, vol. 15, p. 712.

Pyrosmalite in the Broken Hill lode, New South Wales.[1]

By F. L. Stillwell, O.B.E., D.Sc., and John McAndrew, Ph.D., F.G.S.
Melbourne, Australia.

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Summary. Pyrosmalite is a widespread, though very limited, constituent of the Broken Hill lode, and is formed by the hydration and chlorination of the manganese-iron silicates. It is altered in contact with galena and eventually disintegrates into a mat of very fine fibres. The pyrosmalite varies substantially in ratio of Mn/Fe, and two specimens from the rare vughs and fractures gave on analysis ratios of 1·96 and 0·71. The refractive indices decrease slightly with increasing amounts of manganese and water, with a simultaneous small increase in the unit-cell dimensions. The name pyrosmalite is retained for the mineral species in accord with its earlier usage and its recent limitation to the iron-rich variety of an isomorphous series is not endorsed.

THE rare manganese-iron silicate pyrosmalite was first found in the iron mines of Nordmark and Dannemora, Sweden. Published analyses of material from these localities, summarized by Zambonini (1901), reveal a variation in the proportions of manganese and iron; both, however, are major constituents. Frondel and Bauer (1953) have described a manganiferous pyrosmalite from Sterling Hill, New Jersey, and show the clear distinction by X-ray powder pattern of pyrosmalite from the similar minerals friedelite and schallerite.

Pyrosmalite was first recognized at Broken Hill by M. A. Mawby in 1943 (personal communication) in specimens from the No. 12 level Zinc Corporation mine, No. 10 level Broken Hill South mine, and No. 17 level North Broken Hill mine. The identification was confirmed by partial analyses of the samples from the Zinc Corporation and North Broken Hill mines, carried out in the Zinc Corporation assay office. The list of Broken Hill minerals in Woodward (1952), prepared by M. A. Mawby, is the first record of this mineral in the Broken Hill lode.

Pyrosmalite was independently recognized during a petrological study of drill cores from the No. 11 level Junction Mine, North Broken Hill Ltd. Since then it has been found in thin section as a frequent but minor constituent of the manganese silicate bodies within the Broken Hill lode. It occurs in thin section as colourless to very pale brown ragged plates

[1] Published by permission of the Commonwealth Scientific and Industrial Research Organization.

up to 1·5 mm. across which occasionally show a roughly hexagonal outline in near basal sections; a perfect basal cleavage is perpendicular to the optic axis in the uniaxial negative interference figure. The refractive indices of the mineral were determined in sodium light on the analysed samples and on particles excavated from polished sections. The extreme values obtained were: ω 1·664 and 1·682, both $\pm$0·002, ϵ 1·634$\pm$0·002 and 1·650$\pm$0·003.

Crystals of pyrosmalite occur in a vugh bordering calcite within a pocket of blende that bulged from an inch-thick seam of blende through bustamite and manganhedenbergite, in the east leg of the ore body at the 1370-foot level, Broken Hill South mine. The crystals are well formed hexagonal plates up to 3 cm. in width and up to 1·5 cm. thick; many are less than $\frac{1}{2}$ cm. across. The pyrosmalite is coated by quartz crystals, which partially line the vugh; both pyrosmalite and quartz are partially covered with a thin black film comparable in composition with sturtite (Hodge-Smith, 1930), which gives an X-ray diffraction pattern consisting of three diffuse lines at spacings of 4·37, 2·62, and 1·56 Å. The crystals are pale brown with a pearly lustre on the basal pinacoids, in contrast to the prism faces which vary from rose-pink to darker reddish-brown, and have a vitreous lustre.

Mawby's specimen of pyrosmalite, from about 75 feet above the 1700-foot level, North Broken Hill mine, is part of a large crystal 1 cm. thick along a joint or fracture plane through rhodonite and garnet. It is pale brown in colour and has the basal cleavage parallel to the fracture and a prismatic parting perpendicular to this cleavage.

Crystallography. The tabular crystals in the vugh from the Broken Hill South mine consist of the basal pinacoid in combination with the hexagonal prism $(10\bar{1}0)$; an intergrowth of such crystals is shown in fig. 1. Rhombohedral faces are rare, as narrow facets truncating the junction of prism and pinacoid. These crystals are of similar morphology to some from the Swedish occurrences (Flink, 1917). The blocky texture of the prism and pinacoid, and the re-entrant angles on some prism faces, reveal that most larger crystals are a sub-parallel intergrowth of smaller crystals. The internal anastomosing network seen within the crystals in transmitted light is visible in fig. 1.

An X-ray Laue photograph taken with the beam incident along the *c*-axis reveals that the crystals are trigonal, with a Laue symmetry of $\bar{3}\,m$; the symmetry planes are at 30° to the prism faces. A weak single-crystal oscillation photograph about the intersection of prism and pinacoid determines the repetition period of this direction as 13·3 Å.

The X-ray powder pattern, table I, indexes very well for a unit cell of dimensions a 13·36, c 7·16 Å., corresponding to that found for pyrosmalite by Frondel and Bauer (1953) and slightly below the dimensions given by Gossner and Mussgnug (1931).

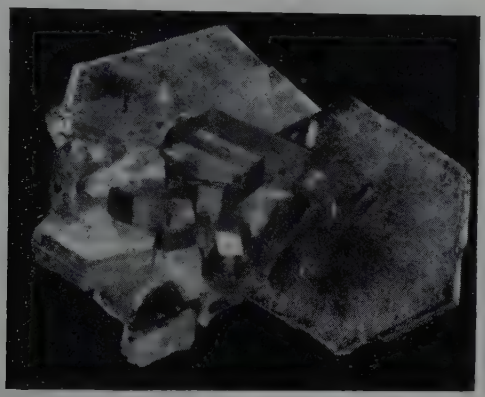


FIG. 1. Cluster of crystals of pyrosmalite from vugh, 1370-foot level, section J2i, Broken Hill South mine. Transmitted dark ground illumination combined with oblique incident illumination. ×8.

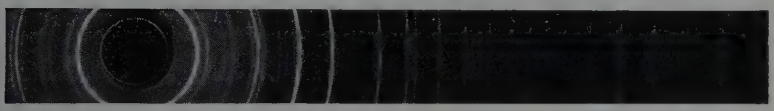


FIG. 2. X-ray powder pattern of pyrosmalite, about 75 feet above 1700-foot level, No. 11 section, North Broken Hill mine. Fe radiation, Mn filter.

The possible space-groups are $P321$, $P3m1$, or $P\bar{3}m1$, in agreement with that found by Gossner and Mussgnug assuming holohedral symmetry. The indexing given in table I reveals more possible diffracting planes than are given by Frondel and Bauer. It was found that the five sets of lattice planes of spacing greater than 2·47 Å. that do not give visible diffractions on the powder pattern are all of type $3.k.\overline{k+3}.l$ with k positive.

The X-ray powder patterns obtained from Broken Hill pyrosmalites of different composition are identical except for slight variation in position of some of the back-diffraction lines. One pattern is listed in table I. Relative to other lines the basal $000l$ diffractions have only a half to

TABLE I. X-ray powder pattern of pyrosmalite, North Broken Hill mine, New South Wales (a = 13·36, c = 7·16 Å., Fe radiation, Mn filter).

As the symmetry is trigonal many of the indices refer to more than one form.

$I.$	d (meas.).	$hk\bar{i}l.$	d (calc.).
2	11·5 Å.	$10\bar{1}0$	11·57 Å.
8	7·16	0001	7·16
½	6·65	$11\bar{2}0$	6·68
3	6·06	$10\bar{1}1$	6·09
½	5·74	$20\bar{2}0$	5·78
½	4·87	$11\bar{2}1$	4·88
1	4·50	$20\bar{2}1$	4·50
2	4·35	$21\bar{3}0$	4·37
2	3·73	$21\bar{3}1$	3·73
5	3·58	0002	3·58
4	3·41	$10\bar{1}2$	3·42
		$30\bar{3}1$	3·40
½	3·34	$22\bar{4}0$	3·34
tr.	3·15	$11\bar{2}2$	3·15
2	3·03	$20\bar{2}2$	3·04
		$22\bar{4}1$	3·03
1	2·89	$40\bar{4}0$	2·892
1	2·77	$21\bar{3}2$	2·770
10	2·69	$40\bar{4}1$	2·682
tr.	2·61	$30\bar{3}2$	2·624
½	2·52	$41\bar{5}0$	2·525
1	2·38	$31\bar{4}2$	2·390
		0003	2·387
		$41\bar{5}1$	2·381
7	2·25	$40\bar{4}2$	2·250
		$11\bar{2}3$	2·248
tr.	2·20	$20\bar{2}3$	2·206
		$50\bar{5}1$	2·202
		$42\bar{6}0$	2·187
tr.	2·13	$32\bar{5}2$	2·132
		$33\bar{6}1$	2·126
		$21\bar{3}3$	2·095
½	2·09	$42\bar{6}1$	2·091
		$51\bar{6}0$	2·078
tr.	2·02	$30\bar{3}3$	2·030
tr.	1·930	$60\bar{6}0$	1·928
tr.	1·912	$31\bar{4}3$	1·915
tr.	1·892	$33\bar{6}2$	1·891
5	1·840	$40\bar{4}3$	1·841
		$43\bar{7}1$	1·838
tr.	1·797	$51\bar{6}2$	1·797
		$52\bar{7}1$	1·794
½	1·766	$10\bar{1}4$	1·769
		$61\bar{7}0$	1·764
tr.	1·734	$41\bar{5}3$	1·734
		$11\bar{2}4$	1·729
5	1·672	$44\bar{8}0$	1·670
4	1·629 Å.	$33\bar{6}3$	1·628 Å.
		$44\bar{8}1$	1·626
tr.	1·608	$53\bar{8}1$	1·610
		$70\bar{7}1$	1·610
tr.	1·588	$61\bar{7}2$	1·583
tr.	1·566	$51\bar{6}3$	1·567
		$62\bar{8}1$	1·566
		$31\bar{4}4$	1·563
5	1·521	$40\bar{4}4$	1·522
½ br.	1·459	$62\bar{8}2$	1·464
		$52\bar{7}3$	1·463
		$41\bar{5}4$	1·460
		$63\bar{9}0$	1·458
tr.	1·427	0005	1·432
		$63\bar{9}1$	1·428
4	1·419	$10\bar{1}5$	1·421
		$61\bar{7}3$	1·419
		$80\bar{8}1$	1·417
		$50\bar{5}4$	1·416
tr.	1·397	$11\bar{2}5$	1·400
		$33\bar{6}4$	1·395
2	1·370	$54\bar{9}2$	1·369
		$44\bar{8}3$	1·368
2	1·342	$30\bar{3}5$	1·342
		$80\bar{8}2$	1·340
tr.	1·287	$71\bar{8}3$	1·289
		$52\bar{7}4$	1·287
		$90\bar{9}0$	1·286
3	1·282	$40\bar{4}5$	1·283
		$7.3.\bar{1}0.1$	1·281
½	1·268	$81\bar{9}2$	1·267
		$90\bar{9}1$	1·265
tr.	1·259	$32\bar{5}5$	1·260
		$54\bar{9}3$	1·259
		$61\bar{7}4$	1·257
tr.	1·245	$41\bar{5}5$	1·245
		$63\bar{9}3$	1·244
		$6.4.\bar{1}0.2$	1·244
		$8.2.\bar{1}0.1$	1·243
3	1·238	$80\bar{8}3$	1·236
tr.	1·226	$7.3.\bar{1}0.2$	1·223
tr.	1·216	$50\bar{5}5$	1·218
		$72\bar{9}3$	1·216
		$53\bar{8}4$	1·214
		$70\bar{7}4$	1·214
tr.	1·192	0006	1·193
		$8.2.\bar{1}0.2$	1·191

$I.$	d (meas.).
½	1·178
tr.	1·152
½	1·142
4	1·126
tr.	1·118
1	1·102
tr.	1·094
2	1·0873
4	1·0820
tr.	1·060
4	1·0472
½	1·0298
½	1·0180
½	1·0100
tr.	1·0055
5	0·9953

two-thirds the intensity given by Frondel and Bauer (1953). As preferred orientation was avoided by using approximately equidimensional fragments and ball-shaped mounts, the patterns suggest that the intensities of basal diffractions given by Frondel and Bauer are enhanced by pre-

ferred orientation of platy cleavage fragments. The weakness or absence of some high-angle diffractions in the data of Frondel and Bauer as compared with table I may result from a greater amount of grinding (cf. McAndrew, 1952).

Chemical composition. An analysis of fragments of a few small crystals of pyrosmalite from the vugh at the 1370-foot level, Broken Hill South mine, carefully freed from the coating of quartz and sturtite, is given in table II, together with an analysis of pyrosmalite from the specimen of M. A. Mawby from the North Broken Hill mine.

The low total of both analyses is noticeable. The atomic ratio of Si to R^{2+} is slightly below the integral ratio of 12:16, suggesting either that the figures for silica may be slightly low, or that an element that substitutes for silicon has not been determined. The latter is probable, as As replaces Si in the related schallerite, and although not sought in the analysis, As was subsequently found to be present in the North mine specimen by a qualitative test.

TABLE II. Chemical analyses and unit-cell contents of Pyrosmalite, Broken Hill, New South Wales.

	(1)	(2)		(1*a*)		(2*a*)	
FeO	17·05	30·58	Fe	5·02	15·84	8·99	16·13
MnO	32·96	21·51	Mn	9·83		6·40	
ZnO	1·92	1·08	Zn	0·50		0·28	
CaO	1·29	1·21	Ca	0·49		0·46	
MgO	tr.	nil					
SiO_2	33·42	34·18	Si	11·76		12·01	
Al_2O_3	nil	nil					
Fe_2O_3	nil	nil	O	29·52		30·05	
Cl	3·78	3·79					
H_2O+	9·36	7·65	OH	17·41	19·67	17·93	20·19
H_2O-	0·07	0·04	Cl	2·26		2·26	
	99·85	100·04	H_2O	2·28		0·00	
Less O for Cl	0·85	0·85					
			Σ (O, OH, Cl, H_2O)	51·47		50·24	
Total	99·00	99·19					
D (meas.)	3·11	3·14					

(1) Pyrosmalite, crystals from vugh, 1370-foot level, section J2i, Broken Hill South mine, Broken Hill. Analyst, G. C. Carlos.

(2) Pyrosmalite, about 75 feet above 1700-foot level, no. 11 section North Broken Hill mine, Broken Hill. Analyst, G. C. Carlos.

(1*a*, 2*a*) Empirical unit-cell contents.

The unit-cell contents of pyrosmalite from the North Broken Hill mine correspond closely to $2[(Fe,Mn,Ca,Zn)_8Si_6O_{15}(OH,Cl)_{10}]$, putting determined H_2O as OH, in agreement with the cell contents found by Gossner and Mussgnug (1931) and by Frondel and Bauer (1953) as recomputed by Hey (1956). The crystals from the Broken Hill South

mine contain appreciably more water. To obtain their cell contents in a form suitable for comparison, the determined O and H_2O is split into O, OH, and H_2O on the assumption that silica is slightly low. The oxygen content is taken as 30·00 less the oxygen equivalent of the deficiency of Si below 12·00, thereby also fixing OH and H_2O. Computed in this manner, the analysis of column 1, table II, gives a unit-cell content close to $2[(Mn,Fe,Zn,Ca)_8Si_6O_{15}(OH,Cl)_{10}1{\cdot}1H_2O]$.

The proportion of Mn:Fe varies from 2:1 in analysis 1 to 2:3 in analysis 2, and it is unlikely that these ratios indicate the limits of variation in pyrosmalite at Broken Hill; the crystals are intermediate in ratio of Mn:Fe between the Swedish and Sterling Hill pyrosmalites. Their water content is appreciably higher than the highest value of 8·55 % recorded for pyrosmalite from Sweden (Gorgeu, 1884 *b*), but is comparable with the 9·60 % of water reported in the related mineral friedelite from the Hautes Pyrénées by Gorgeu (1884*a*). The water content of pyrosmalite is evidently variable. The anion content of the unit cell is close to $2[O_{15}(OH,Cl)_{10}]$ and $2[O_{15}(OH,Cl)_{10}.1{\cdot}1\,H_2O]$ in the two analysed specimens from Broken Hill. Although the Sterling Hill pyrosmalite has a water content intermediate between that of these two specimens, the anion unit-cell content is close to $2[(O,OH)_{15}(OH,Cl)_{10}]$ (Hey, 1956), requiring some substitution of OH for O but no excess of total anions above fifty, in contrast to the crystals from the Broken Hill South mine.

Variation. The variation in chemical composition of pyrosmalite is accompanied by a small although distinct variation in other properties. These are summarized in table III and compared with the Sterling Hill pyrosmalite, Frondel and Bauer (1953).

TABLE III. Variation in properties of Pyrosmalite.

Composition.	ω.	ϵ.	Spacing of high-angle lines in X-ray pattern, Å.			Locality.
Not analysed	1·682	1·650	1·0835		0·9938	Broken Hill
$(Fe_{0\cdot55}Mn_{0\cdot40}Zn_{0\cdot02}Ca_{0\cdot03})_8Si_6O_{15}(OH,Cl)_{10}$	1·670	1·639	1·0873	1·0820	0·9953	Broken Hill
$(Mn_{0\cdot62}Fe_{0\cdot32}Zn_{0\cdot03}Ca_{0\cdot03})_8Si_6O_{15}(OH,Cl)_{10}1{\cdot}1\,H_2O$	1·664	1·634	1·0890	1·0862	0·9983	Broken Hill
$(Mn_{0\cdot72}Fe_{0\cdot23}Mg_{0\cdot02}Zn_{0\cdot03})_8Si_6O_{15}(OH,Cl)_{10}$	1·669	1·631	—	—	—	Sterling Hill

It can be observed, table III, that the refractive index decreases slightly with increasing amount of manganese and of water, with a simultaneous increase in the cell dimensions. The highest refractive index and lowest cell dimensions occur in pyrosmalite that is associated with dannemorite and pyroxmangite, and presumably rich in iron.

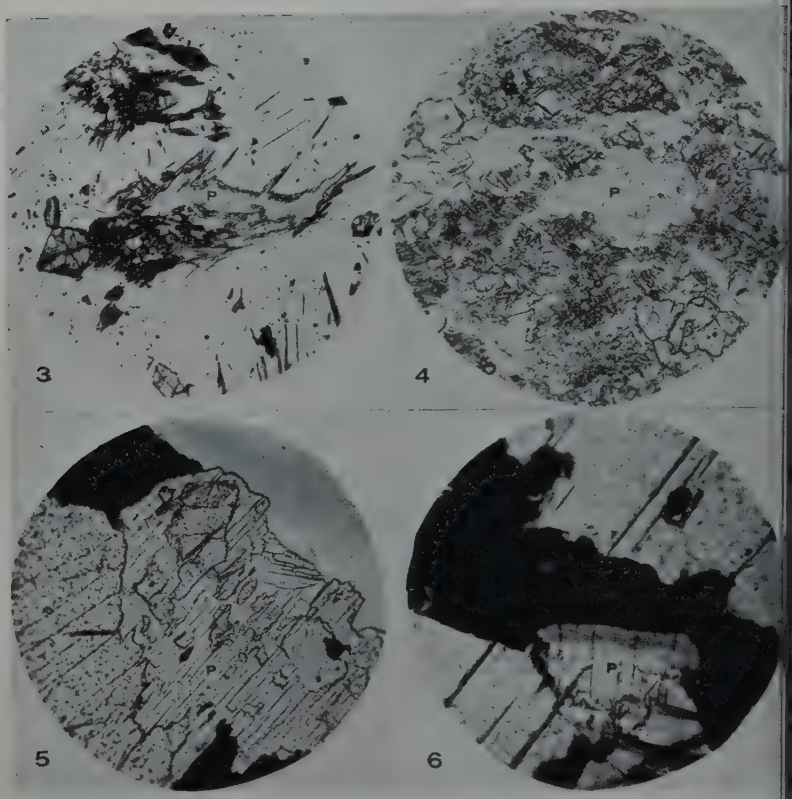
The increase in cell dimensions is best revealed by the position of the

strong line in the X-ray powder pattern at a diffraction angle of about 150°, which varies in spacing from 0·9938 to 0·9983 Å. in patterns obtained from narrow, weakly absorbing specimens in which systematic displacement of line position is a minimum (Straumanis, 1949). The variation in separation of the doublet with spacings of approximately 1·087 and 1·082 Å. reveals a variation in the axial ratio, c/a.

The ratio of Mn:Fe is 2:1 in the crystals from the Broken Hill South mine, intermediate between the highest value of 1·05:1 recorded for Swedish material (Zambonini, 1901) and the ratio 3·2:1 in pyrosmalite from Sterling Hill (Frondel and Bauer, 1953). Frondel and Bauer describe the manganese-rich mineral from Sterling Hill as manganpyrosmalite, and are followed by Hutton (1956) for a Broken Hill specimen. In doing so, they relegate the name pyrosmalite from that for a species as found with approximately equal amounts of Fe and Mn to that of a variety with Fe>Mn; this departure from the earlier usage is undesirable. The name pyrosmalite is here retained for all members of the isomorphous series. The small differences in optical properties with variation in the Mn:Fe ratio render varietal distinctions inapplicable to petrological studies in thin section, where the mineral is identified without the possibility or necessity of chemical analysis.

It may be noted that the name manganpyrosmalite was first used by M. Bauer (1885) in a review of Gorgeu's paper (1884*a*). Bauer suggested that friedelite might be 'ein FeOfreier Manganpyrosmalith', using the name for a hypothetical end-member.

Occurrence. Specimens of pyrosmalite from vughs and fractures, such as have been analysed, are rare in Broken Hill. Nevertheless, pyrosmalite is a widespread, though very minor, mineral in the large bodies of the manganese silicates occurring in the Broken Hill lode. It is commonly found with galena or in the neighbourhood of galena on the margins or grain boundaries of rhodonite, knebelite, bustamite, and manganhedenbergite; it appears sometimes in the interstices between garnets or in veinlets in a garnet quartzite. In many instances it is clearly derived by replacement of the anhydrous manganese silicates; it occurs rather abundantly in the massive rhodonite and garnet that is attached to the specimen of pyrosmalite from the North Broken Hill mine and ragged unreplaced residuals of rhodonite are embedded in it (fig. 4). Unreplaced residuals of knebelite within a plate of pyrosmalite are shown in fig. 5 and the similar orientation of both large and small residuals indicates that they have been derived from a single crystal. The varying proportion of manganese to iron in pyrosmalite can be



FIGS. 3–6.

FIG. 3. Ragged plate of pyrosmalite (*P*) in quartz, with associated dannemorite (low left), galena, garnet, and needles of dannemorite or actinolite. D.D. 588 at 89 fee No. 11 level, Junction mine, North Broken Hill Ltd. ×13.

FIG. 4. Pyrosmalite (*P*) replacing rhodonite, with some garnet at lower righ Section mounted in medium with a refractive index of 1·66 to reduce relief. Abo 75 feet above 1700-foot level, No. 11 section, North Broken Hill mine. ×20.

FIG. 5. Pyrosmalite (*P*) enclosing unreplaced residuals of roepperite (zinc-bearir knebelite). Black areas are galena. Junction North mine, North Broken H Ltd. ×60.

FIG. 6. Pyrosmalite (*P*) showing alteration along the contact with galena (blac within a crystal of rhodonite. The cleavage of the pyrosmalite extends into t altered margin and the cleavage of the rhodonite extends as a crack into py osmalite. King shaft ore body, D.D. 602, between 24 feet and 30 feet, No. 10 lev Junction mine, North Broken Hill Ltd. ×60.

expected to be a reflection of the varying proportions of manganese to iron in the replaced silicate. The small percentage of lime may likewise be derived from the replaced silicate and it is possible that the small percentage of zinc may come from the same source. The widespread occurrence of apatite within the bodies of manganese silicates reveals the presence of chlorine in the early stages of lode formation.

The common association of pyrosmalite with galena within the bodies of manganese silicates indicates that this type of hydration and chlorination of the manganese silicates occurs with the introduction of the sulphides. Pyrosmalite is thus a late hydrous manganese silicate in contrast to the early or high-temperature anhydrous silicates—rhodonite, pyroxmangite, knebelite, bustamite, and manganhedenbergite. This type of hydration of the manganese silicates is limited in degree and is probably much less than the hydration that produces bementite, sturtite, or their equivalents.

Pyrosmalite is not found associated with blende in the same way as with galena, and one can surmise that in the presence of blende the available manganese and iron is absorbed in the composition of the latter. Blende occurring with pyrosmalite from the vugh from the 1370-foot level, Broken Hill South mine, contains 1·56 % Mn and 11·66 % Fe.

When pyrosmalite is observed in small particles in thin sections, it is apt to be confused with a colourless mica from which it is distinguished by a higher refractive index and a strictly uniaxial interference figure. Moreover, pyrosmalite undergoes alteration to a greenish mineral with a faint but distinct pleochroism. This alteration is shown in fig. 6 along a contact with galena in a crystal of rhodonite. The altered zone is finely fibrous between crossed nicols with the fibres at right angles to the contact and parallel to the cleavage of pyrosmalite. This greenish mineral is often observed within galena in rhodonitic ore, where it has been found to have a negative uniaxial figure, high birefringence, and refractive indices straddling 1·54; its identity is uncertain but it appears comparable, except in colour, with parsettensite, another hydrous manganese silicate. Finely fibrous margins from this mineral have been observed to extend into the surrounding galena and may indicate the origin of the clusters of very fine fibres that are commonly observed in galena on a polished surface of rhodonitic ore but are too thin to be clearly observed in thin section. These fibres have not been observed in blende, which, in contrast to galena, contains some manganese in its composition.

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References.

Bauer (M.), 1885. Neues Jahrb. Min., vol. 2, Ref. p. 404.
Flink (G.), 1917. Arkiv Kemi, Min., Geol., vol. 6, no. 21.
Frondel (C.) and Bauer (L. H.), 1953. Amer. Min., vol. 38, p. 755 [M.A. **12**–236].
Gorgeu (A.), 1884*a*. Compt. Rend. Acad. Sci. Paris, vol. 98, p. 586.
—— 1884*b*. Bull. Soc. Min. France, vol. 7, p. 58.
Gossner (B.) and Mussgnug (F.), 1931. Zeits. Krist., vol. 76, p. 525 [M.A. **5**–28].
Hey (M. H.), 1956. Amer. Min., vol. 41, p. 134 [M.A. **13**–125].
Hodge-Smith (T.), 1930. Rec. Australian Mus., vol. 17, p. 410 [M.A. **4**–345].
Hutton (C. Osborne), 1956. Amer. Min., vol. 41, p. 581.
McAndrew (J.), 1952. Ibid., vol. 37, p. 453 [M.A. **12**–93].
Straumanis (M. E.), 1949. Journ. Appl. Physics, vol. 20, p. 726.
Woodward (O. H.), 1952. A review of the Broken Hill lead-silver-zinc industry. Australian Inst. Min. Met., Melbourne.
Zambonini (F.), 1901. Zeits. Kryst. Min., vol. 34, p. 549.

Dickite from sandstones in northern England and North Wales.

(With Plate XIII.)

By Frank Smithson, D.Sc.,
University College of North Wales, Bangor,
and George Brown, B.Sc.,
Rothamsted Experimental Station, Harpenden.

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Summary. The occurrence of dickite as a rock-forming mineral in sandstones of the Lower Carboniferous Series, the Millstone Grit, and the Middle Jurassic has been reported previously by the authors. In view of the paucity of data on this mineral, six samples were purified and examined optically, by staining tests, and by the X-ray powder method. In addition, a chemical analysis, a differential thermal analysis, and a thermal weight-loss curve were made on the purest sample. The investigations confirm the identity of the material.

As a result of his microscopic studies, Dick believed that there were two varieties of kaolinite and recorded that the optically positive and 'better crystallized type', now known as dickite, occurred at Amlwch, Anglesey (Dick, 1888; Miers, 1888, 1890), at Bolton Abbey, Yorkshire, at Newcastle upon Tyne, and at Congleton, Cheshire (Dick, 1908). Ross and Kerr (1931) have suggested that the earliest observation of this mineral was that by Knop (1859) who described 'orthorhombic' crystals of kaolin occurring at Schneckenstein. Of these early examples only the Amlwch material appears to have been still available when Ross and Kerr made their X-ray studies that led them to propose a specific name for it. Other dickite localities they name are in the U.S.A. (Arkansas, Colorado, Iowa, and Oklahoma), Mexico, Peru, and Silesia. Dickite has been subsequently proved by X-ray methods in Pennsylvania (Honess and Williams, 1935), Missouri (Tarr and Keller, 1936), Utah and New Mexico (Kerr *et al.*, 1950), at Newcastle upon Tyne (mentioned by Boswell, 1933, when abstracting Tomkieff, 1927), in County Durham (Dunham, Claringbull, and Bannister, 1948), in Yorkshire (Hemingway and Brindley, 1948, Brindley, 1951), and in South Africa (Frankel, 1949).

In all the above cases the mineral is apparently restricted to veins, pockets, cavities, &c., and does not enter into the composition of the

rock as a rock-forming mineral except at Congleton, where Dick found that in the Millstone Grit 'the mineral fills the spaces between the grains of the grit'. Although this example has not been tested by X-ray methods, proved dickite occurs in this manner in parts of North Wales and northern England (Brown and Smithson, 1953; Smithson, with appendix by Brown, 1954) and from these occurrences the samples described in the present paper have been taken. Our earlier papers dealt chiefly with the petrography of the kaolin-bearing sandstones and, in the Middle Jurassic, indicated the geographical boundary between dickite- and kaolinite-bearing strata, showing that the former were characterized by more severe diagenesis than the latter. The present paper gives a detailed account of the X-ray identification and results of some optical tests on six representative samples, enumerated in the next section.

Without entering into details concerning the origin of dickite it may be pointed out that whereas hydrothermal activity has often been regarded as the sole or major cause of the formation of dickite, the present examples are not associated with ore-bearing veins nor with any known or probable magmas.

The source rocks (F. S.).

The stratigraphical horizons, localities, and general appearance of the six dickite sandstones are as follows:

No. 1. Carboniferous, Carboniferous Limestone Series, Bangor, Caernarvonshire, about 1000 yards north-east of Menai suspension bridge. Fissile sandstones with coaly plant remains, much limonitic matter and inconspicuous dickite.

No. 2. Carboniferous, Millstone Grit, Bodorgan Shore, Anglesey, about 1500 yards south-west of the bridge, Pont Malldraeth. Very coarse sandstone speckled white with dickite and brown with limonitic matter (pl. XIII, fig. 1).

No. 3. Carboniferous, Millstone Grit, about ½ mile west of Ellingstring, near Masham, Yorkshire. Coarse sandstone with some large felspar grains; interstitial dickite white to buff.

No. 4. Jurassic, Lower Estuarine Series (Lower Deltaic Series),[1] cliff near West Pier, Whitby, Yorkshire. Soft sandstone slightly mottled yellow and white.

[1] The Lower Estuarine Series (Geol. Surv.) includes the Lower Deltaic Series of Hemingway (1949) and part of his Middle Deltaic Series.

No. 5. Jurassic, Lower Estuarine Series (Lower Deltaic Series), escarpment above Crag Pond, Farndale, Yorkshire. Yellow sandstone faintly speckled with dickite.

No. 6. Jurassic, Lower Estuarine Series (Middle Deltaic Series), 200 yards below road-bridge, Bondfield Gill, about 6 miles north of Helmsley, Yorkshire. Yellow sandstone with vertical carbonaceous markings (stems of Equisetum (?)). The rock is speckled with dickite particularly in the fossil stems, which also contain limonitic matter.

Microscopical examination (F. S.).

Examination of thin sections of the sandstones shows interstices packed with dickite in the form of rouleaux (pl. XIII, fig. 2). Such bodies are often regarded as piles of platy crystals, though it may be more accurate to interpret them as columnar crystals, which, owing to flexibility and ready basal cleavage, have suffered distortion and dislocation as they jostled one another during growth.

The separated material (pl. XIII, figs. 3–6) contains both rouleaux and plates, the latter ranging from almost regular hexagons to elongated and rhombic shapes or complex figures with re-entrant angles (Smithson, 1954, fig. 1). Plates with diameters from 5μ to 50μ were encountered, but most lay well within those limits. All but the thinnest plates showed changes of colour on rotation when using a sensitive purple gypsum plate and crossed polars, and this test showed the fast-ray vibration direction to be parallel to two sides of the hexagon. The birefringence is sufficient to give slight 'twinkling' if phase-contrast equipment, a single polar, and an appropriate immersion liquid are used (Smithson, 1948). This arrangement was adopted for determining the refractive indices for sodium light, using a series of liquids with intervals of 0·001 as measured on an Abbé refractometer at 20° C. Dickite plates adhered flat on the glass, but rouleaux were variously oriented and liable to movement. With plates the slow vibration direction (γ) gave values 1·567–1·568, and the fast direction 1·564–1·565. Since rouleaux appropriately oriented will give a correct value of α a number were tested in each sample and the lowest values, 1·562–1·563, were taken as a measure of this index.

With appropriate stains the plates become coloured, though feebly and with little or no pleochroism, i.e. the absorptions for Y and Z are practically identical. With the same stains the rouleaux are more strongly coloured and pleochroic, the absorptions for X being distinct from those for Y and Z (table I).

TABLE I. Pleochroism of stained dickite.

Stain.	*X*.	*Y*.	*Z*.
Safranin	Yellow	Pink	Pink
Thionin	Yellow	Bluish-violet	Pinkish violet
Crystal Violet	Yellow or brown	Violet	Violet
Malachite Green	Violet	Blue-green	Blue-green
Nile Blue	Violet	Pale blue	Pale blue
Methylene Blue	Almost colourless	Blue	Blue

In the dickite separations, particularly nos. 5 and 6, there are what appear to be aggregates of a cryptocrystalline clay mineral (pl. XIII, fig. 6) that have a mean refractive index about 1·565 and take a deep stain with malachite green.

Non-clay minerals. Of the other minerals present in the source rocks only the following were recognized contaminating the dickite separations: quartz, felspars, and white mica, together with minute particles of the heavy minerals anatase, leucoxene, brookite, rutile, tourmaline, and zircon.

X-ray examination (G. B.).

For X-ray examination the separates obtained from the sandstones by crushing and sieving were purified further. Optical examination had shown that the diameter of the bulk of the hexagonal plates lay well within the range 5 to 50μ but also that in this range of particle size were many aggregates cemented by iron oxides or clay. To disperse these aggregates the separates were warmed in dilute hydrochloric acid for about a minute and washed free of acid immediately. After treatment the powders were white except no. 1, which was grey owing to carbonaceous impurities. No sign of attack by acid on the edges of the delicate hexagonal plates could be seen. Two size-fractions, 5 to 20μ and 20 to 40μ (ideally), were separated by repeated sedimentation giving twelve 10 to 20 mg. samples which were used without further crushing or grinding for X-ray examination. In addition a further one-gram sample of 5 to 40μ material was obtained from no. 2 (which proved to be the purest) by the method outlined above, and this was used for differential thermal analysis, chemical analysis, and thermal weight loss analysis. About 75 % of this 5 to 40μ fraction had diameters in the range 10 to 20μ and the diameters of most of the remainder were in the range 20 to 30μ. As this fraction consists chiefly of hexagonal plates with only a few rouleaux it can be taken that its physical behaviour will be determined almost exclusively by the former.

Powder photographs of unground material were taken in a 9·0 cm. diameter Bradley type evacuated powder camera with filtered Co-$K\alpha$ radiation; a few photographs were also taken with a Cu-$K\alpha$ radiation. The specimens were rotated during exposure. For flaky minerals of low symmetry two particular requirements are good resolution and random orientation of crystallites in the specimen. Narrow specimens were prepared from aggregates obtained by drying viscous slurries of the powders with gum arabic and water on slides, and specimens about $1{\cdot}5 \times 0{\cdot}1 \times 0{\cdot}1$ mm. were cut from the aggregates. The gum arabic acts as binder for the powder and also as a spacer, and if the slurry is viscous it tends to prevent preferred orientation by hindering the settling of the flaky particles on the slide. Narrow specimens have the additional advantage of low absorption and thus line-displacement errors due to absorption can be neglected. Photographs were taken of both coarse and fine fractions and the dominant mineral in all fractions was found to be dickite.

The spacings and visually estimated intensities of lines due to dickite in the different samples have been tabulated and the tables deposited in the library, Rothamsted Experimental Station. Copies may be obtained from the Librarian. Although the patterns were measured only to $d = 1{\cdot}2$ Å., reflections occur to $d = 0{\cdot}8$ Å. Despite the apparent perfection of the microscopically observed crystals (pl. XIII) the α_1, α_2 doublet was not resolved even at the highest θ values.

The powder data for dickite appear to be incomplete (compare Gruner, 1932; Brindley, 1951). The observed reflections from our materials were allocated to dickite or impurities on the basis of Gruner's and Brindley's data and from a knowledge of the microscopically observed impurities in each sample. The impurities detected by X-rays were quartz and anatase in all specimens, mica and feldspar in some. Sample no. 2, 5 to 40μ, is estimated to contain more than 95 % dickite.

All the dickite patterns were identical within experimental error and the average spacings derived from all the measurements are given in table II where they can be compared with Gruner's (1932) and Brindley's (1951) data. The accuracy of the average spacings was estimated to be $\pm 0{\cdot}1$ % by comparing the quartz spacings with A.S.T.M. card 5–0490. The observed reflections all fit Gruner's cell, the differences in lattice constants being within experimental error. For example, the layer thickness, d (002), is given as 7·160 Å. by Gruner (1932). Using the first four visible (00l) spacings we obtain 7·153, 7·156, 7·149, 7·156 Å., and the average 7·154 Å. The observed reflections coincide with the reflections

TABLE II. X-ray powder data for dickite. Col. 2, spacings in Å. and visually estimated intensities, averaged from the detailed data deposited at Rothamsted. Col. 1, indices calculated for Gruner's (1932) unit cell. Cols. 3 and 4, spacings recorded by Gruner (1932) and Brindley (1951) respectively.

1.	2.		3.	4.
002	7·153	vs	7·12	7·17
020, 110	4·451	ms	4·43	4·452
11$\bar{1}$	4·366	ms		4·374
021	4·254	mw		4·273
111	4·118	s	4·15	4·129
11$\bar{2}$	3·953	mw	3·95	3·962
022	3·790	ms	3·79	3·798
004, 112	3·578	vvs	3·578	3·582
11$\bar{3}$	3·428	m	3·439	3·432
023	3·262	w		3·253
113	3·094	mw	3·011	3·103
11$\bar{4}$	2·936	mw		2·937
024	2·794	mw		2·796
114	2·650	vvw	2·634	2·656
13$\bar{1}$, 200 130	2·558	ms	2·566	2·565
11$\bar{5}$	2·524	vvw	2·514	2·523
131, 20$\bar{2}$	2·503	s		2·506
006, 132	2·383	m	2·384	2·388
13$\bar{3}$, 202	2·322	vs	2·328	2·323
220, 133 20$\bar{4}$, 041	2·210	mw	2·180	2·211
026, 22$\bar{3}$	2·105	w	2·099	2·103
22$\bar{4}$, 13$\bar{5}$ 204	1·974	ms	1·976	
223, 11$\bar{7}$	1·935	vvw		
044	1·896	mw	1·895	
027, 135 20$\bar{6}$	1·862	mw	1·859	
22$\bar{5}$	1·850	w		
13$\bar{6}$, 224	1·803	w		
008, 117	1·789	mw	1·792	
045	1·761	vw		
22$\bar{6}$, 11$\bar{8}$	1·717	vw	1·718	
150, 24$\bar{1}$ 31$\bar{1}$, 15$\bar{1}$ 240	1·686	mw		
310, 31$\bar{2}$ 225, 151 24$\bar{2}$, 028	1·669	mw		

1.	2.		3.
15$\bar{2}$, 13$\bar{7}$ 206, 241	1·651	ms	1·649
311, 31$\bar{3}$	1·644	w	
046, 152 24$\bar{3}$	1·626	w	
15$\bar{3}$, 242	1·610	mw	
312, 31$\bar{4}$ 22$\bar{7}$	1·589	vw	
153, 24$\bar{4}$	1·574	vw	
137, 20$\bar{8}$	1·558	mw	1·555
15$\bar{4}$, 11$\bar{9}$ 243, 226	1·548	vw	
313, 31$\bar{5}$	1·525	vw	
047, 13$\bar{8}$	1·509	vw	
154, 24$\bar{5}$ 029	1·502	vw	
060, 33$\bar{1}$	1·488	ms	1·490
22$\bar{8}$	1·469	vw	
062, 33$\bar{3}$ 331, 31$\bar{6}$ 314, 119	1·457	mw	1·455
227, 138 155, 24$\bar{6}$ 0.0.10	1·433	w	1·431
15$\bar{6}$, 245 048, 1.1.$\bar{1}$0 13$\bar{9}$, 208	1·402 1·392	vw w	1·391
315, 31$\bar{7}$ 064, 33$\bar{5}$ 333	1·376	mw	1·374
065, 33$\bar{6}$ 139, 1.1.10 2.0.$\bar{1}$0	1·319	ms	1·317
	1·296	vvw	
	1·289	mw	
	1·279	w	
	1·264	w	
	1·254	mw	
	1·238	mw	

of higher calculated intensity (Gruner, 1932) except for a few of spacing less than 1·5 Å. which would be more sensitive than those of higher spacing.

Chemical analysis (G. B.).

A partial chemical analysis was carried out on about 0·3 g. of the 5 to 40μ separate of no. 2 referred to previously and gave SiO_2 47·4, Al_2O_3 38·0, TiO_2 0·2, H_2O- 0·0, H_2O+ 13·7 = 99·3. Alumina was determined using aluminon (Chenery, 1948) and is the value most likely to be in error. The impurities detected by X-rays in this fraction were quartz and traces of anatase and mica. Assuming these to be the only impurities present in appreciable amounts, calculation from the H_2O+ value leads to a content of approximately 98 % $Al_2O_3.2SiO_2.2H_2O$, the remainder being quartz 1·8 % and anatase 0·2 %.

Thermal examination (G. B.).

The material used for the thermal examination was part of the 5 to 40μ separate from no. 2. Optical examination of this sample showed that about 75 % of the plates had major diameters in the range 10 to 20μ. The largest plates seen were about $40 \times 30\mu$, the smallest $4 \times 3\mu$. For the thermal studies the samples were used in the unground condition.

Weight loss. For this determination duplicate 0·3 g. samples were heated in small platinum boats in a furnace controlled within $\pm 5°$ C. of the recorded value. The specimens were weighed after heating at 50° temperature intervals between 100° and 850° C.; they were held at each temperature for 14 hours which allowed an approach to equilibrium. The resultant curve is shown in fig. 1. The crystals retain their hexagonal shape after heating. Ross and Kerr (1931) gave an equilibrium weight loss curve for dickite from Chihuahua, Mexico, which they describe as vermicular with the average diameter of the crystals about 30μ. Their curve is similar in shape to fig. 1, but the main weight loss occurs in the range 500° to 600° C. in which about 90 % of the water is lost, as opposed to 400° to 550° C. for our material; no explanation can be offered at the moment for the different temperature at which the weight loss occurs. Neither the curve in fig. 1 nor that given by Ross and Kerr (1931) for dickite shows the second break at about 675° C. recorded by Ross and Kerr (1931) and by von Knorring, Brindley, and Hunter (1952) for nacrite, the other mineral of the kaolin group that forms large crystals.

Differential thermal analysis. A curve covering the ranges 200° to 800° C. was made using 0·25 g. with calcined kaolinite as the inert material. The samples were heated in ceramic crucibles suspended in a cavity in a nickel block in an atmosphere of dry nitrogen at a heating rate of 10° per minute. The curve (fig. 2) shows what appear to be two

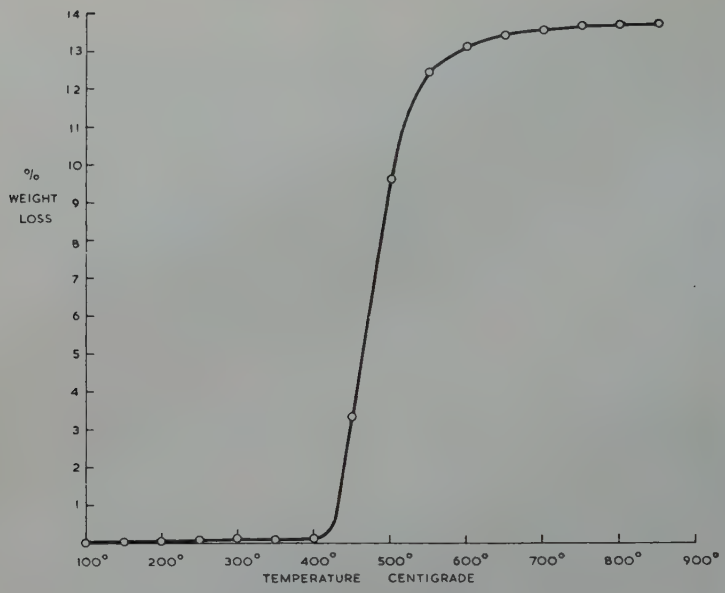


Fig. 1. Thermal weight loss curve for dickite no. 2, 5 to 40μ. 14 hours at each temperature.

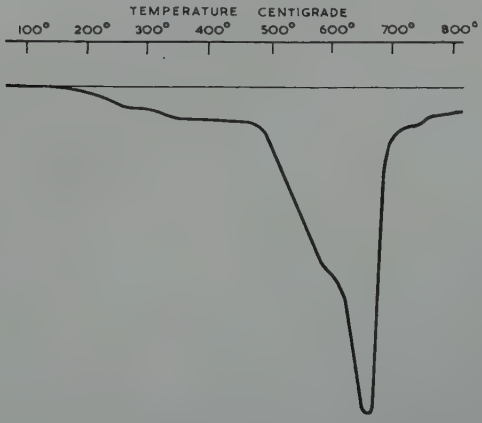


Fig. 2. Differential thermal analysis curve for dickite no. 2, 5 to 40μ.

partially resolved endothermic peaks at about 590° and 670° C. The differential thermal analysis curves given in the literature for dickite often show an asymmetric endothermic peak with a slow approach to the maximum. Kerr and Kulp (1948) show curves of this type and

others in which the endothermic peak is symmetrical, but unfortunately they give no evidence for either identity or purity of the samples. Kerr *et al.* (1950, p. 66) give the differential thermal analysis curve of a dickite from Anglesey (not the type locality) which resembles the curve in fig. 2 although the double endothermic peak is less marked; they suggest that nacrite is present in this material, but give insufficient data to support this.

There are two possible sources for the double peak. Either both peaks are due to dickite and are shown here because of the particular conditions, for example, small range of crystal size with well-developed crystals, or the first peak is due to impurity, the most likely being kaolinite. No X-ray reflections other than those that can be attributed to dickite, quartz, anatase, and mica (see the tables deposited at Rothamsted) were observed from no. 2. In view of the large number of dickite reflections observed, many of them very weak, if kaolinite is present in this material then its detection in the presence of major amounts of dickite must be difficult. The impurities revealed by microscopical examination were minute amounts of quartz, anatase, zircon, muscovite, and unidentifiable particles similar to those shown stained in pl. XIII, fig. 6, and although these may be a cryptocrystalline clay mineral other than dickite, their amount (<1 %) is probably too small to affect the thermal results. On the basis of the X-ray and optical evidence the double endotherm must be tentatively attributed to dickite but it must be borne in mind that it is very difficult to establish purity with fine grained materials.

Discussion of thermal studies. The thermal studies reported above were merely carried out as an adjunct to other methods of identification and lay no claim to completeness. It is interesting to note the difference between the differential thermal analysis curve obtained directly and the differential curve obtained from the weight loss curve. The former shows two unresolved peaks and the peak as a whole is asymmetric with the steeper slope on the high-temperature side, the latter shows only one peak much less asymmetrical with the steeper slope on the low-temperature side. The non-correspondence of the curves emphasizes the dynamic character of the differential thermal curve.

It appears from the literature that kaolinite, dickite, and nacrite differ in their differential thermal and weight loss curves. It is not known how far these differences may be due to differences in crystal structure leading to variations in hydroxyl binding or to factors such as crystal size and perfection, which may affect the reactions. The results of the

present limited study suggest that combined X-ray, weight loss, and differential thermal analyses, made on well-characterized materials with varied narrow ranges of crystal size and with varied rates of heating, might throw considerable light on the mechanism of the dehydroxylation reactions. Until such a study is made, interpretations based on differences in the differential thermal analysis endothermic peaks of clay minerals in the region 500° to 800° C. must be made with caution.

References.

A.S.T.M. Index of X-ray Diffraction Data, 1953. American Society for Testing Materials, Philadelphia.

Boswell (P. G. H.), 1933. On the Mineralogy of Sedimentary Rocks. Murby, London [M.A. **5**–340].

Brindley (G. W.), 1951. Chapter II. X-ray Identification and Crystal Structures of Clay Minerals. Min. Soc., London [M.A. **11**–253].

Brown (G.) and Smithson (F.), 1953. Nature, vol. 172, p. 317 [M.A. **12**–490].

Chenery (E. M.), 1948. Analyst, vol. 73, p. 501.

Dick (A. B.), 1888. Min. Mag., vol. 8, p. 15.

—— 1908. Ibid., vol. 15, p. 124.

Dunham (K. C.), Claringbull (G. F.), and Bannister (F. A.), 1948. Ibid., vol. 28, p. 338.

Frankel (J. J.), 1949. Ibid., vol. 28, p. 582.

Gruner (J. W.), 1932. Zeits. Krist., vol. 83, p. 394 [M.A. **5**–325].

Hemingway (J. E.), 1949. Geol. Mag., vol. 86, p. 67.

—— and Brindley (G. W.), 1948. Rep. 18th Internat. Geol. Congr., London. Part 13, p. 308.

Honess (A. P.) and Williams (F. J.), 1935. Amer. Min., vol. 20, p. 462 [M.A. **6**–137].

Kerr (P. F.) and Kulp (J. L.), 1948. Amer. Min., vol. 33, p. 387 [M.A. **10**–549].

—— *et al.*, 1950. Amer. Petr. Inst., Clay Mineral Standards, Preliminary Reports No. 7, Columbia University, New York [M.A. **10**–216].

Knop (A.), 1859. Neues Jahrb. Min., p. 593.

Miers (H. A.), 1888. Min. Mag., vol. 8, p. 25.

—— 1890. Ibid., vol. 9, p. 4.

Ross (C. S.) and Kerr (P. F.), 1931. U.S. Geol. Surv. Prof. Paper 165 E, p. 151 [M.A. **5**–359].

Smithson (F.), 1948. Min. Mag., vol. 28, p. 384.

—— 1954. Geol. Mag., vol. 91, p. 177 [M.A. **12**–491].

Tarr (W. A.) and Keller (W. D.), 1936. Amer. Min., vol. 21, p. 109 [M.A. **6**–373].

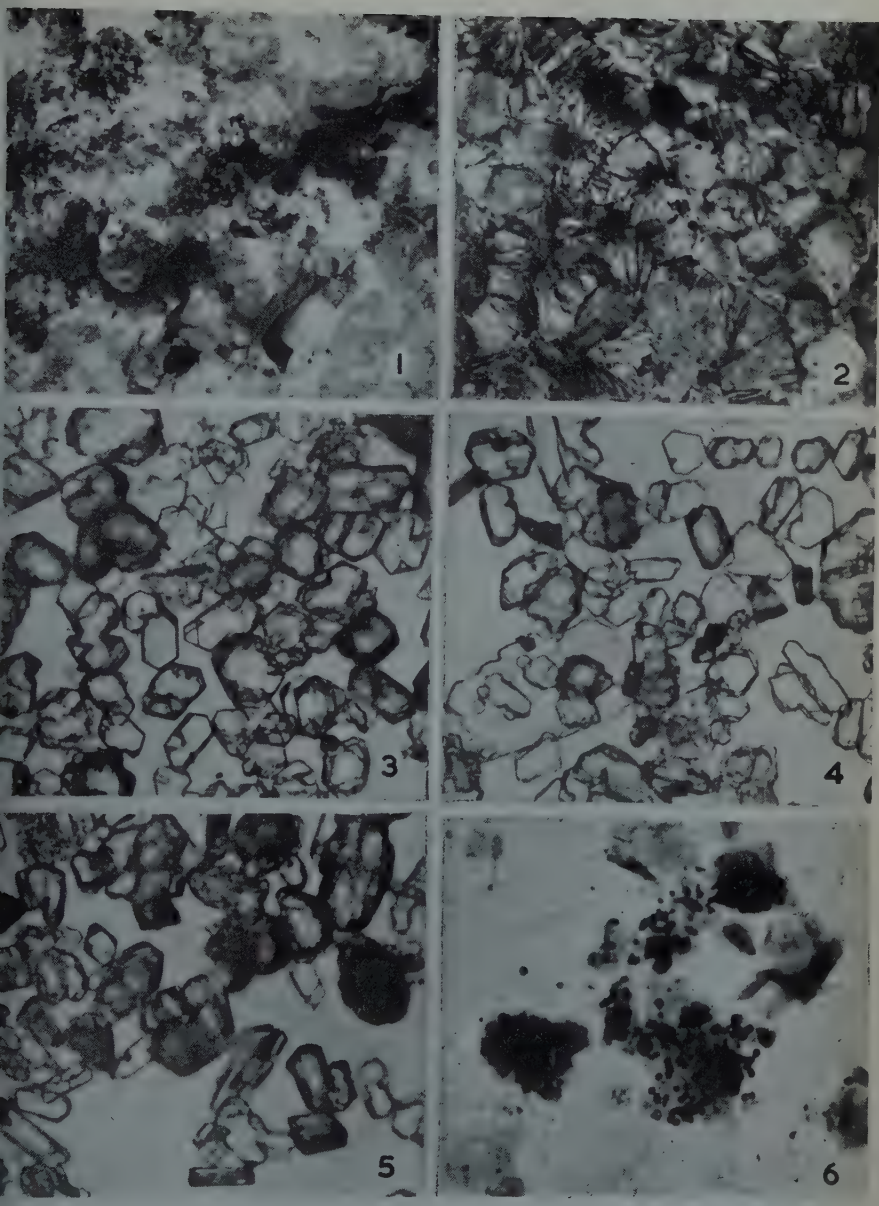
Tomkieff (S.), 1927. Proc. Geol. Assoc., vol. 38, p. 518 [M.A. **3**–555].

Von Knorring (O.), Brindley (G. W.), and Hunter (K.), 1952. Min. Mag., vol. 29, p. 963.

Explanation of Plate XIII.

Fig. 1. Broken surface of dickite-bearing Millstone Grit, Bodorgan shore, Anglesey (source rock no. 2). ×9.

Fig. 2. Dickite in thin section of above. ×500.



F. Smithson and G. Brown: Dickite

FIG. 3. Dickite in coarse silt fraction from source rock no. 2. In air. ×432.

FIG. 4. Dickite in coarse silt fraction from Lower Estuarine sandstone, Whitby, Yorks. (source rock no. 4). The large flake is muscovite. In air. ×432.

FIG. 5. Dickite in coarse silt fraction from Lower Estuarine sandstone, Farndale, Yorks. (source rock no. 5). Particle near centre shows splitting along cleavage planes. In air. ×432.

FIG. 6. As no. 5, stained with malachite green to show the associated cryptocrystalline clay mineral (?) and mounted in Canada balsam. ×1025.

Abraded pyrite crystals from the Witwatersrand gold mines.

By J. J. Frankel, D.Sc., F.G.S., A.M.I.M.M.
Department of Geology, University of Natal, Durban.

[Taken as read 24 January 1957.]

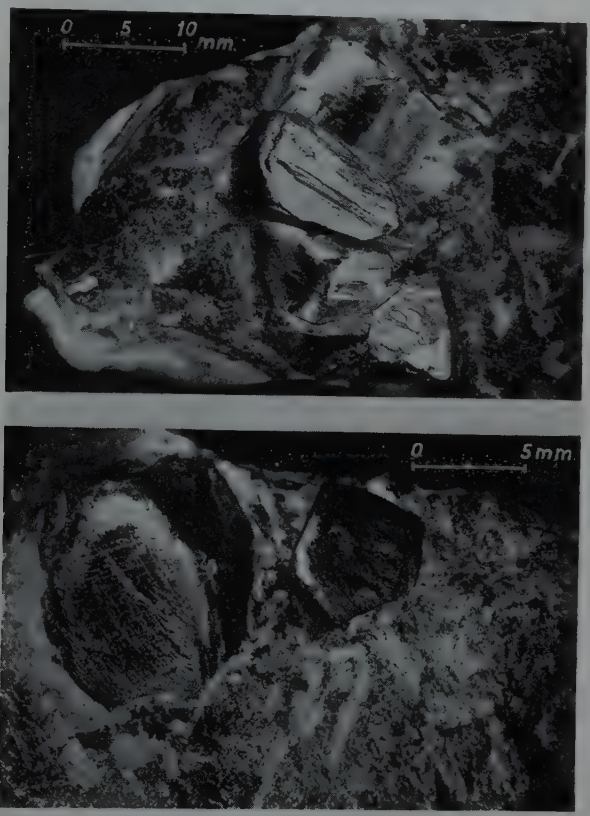
Summary. Metamorphosed dyke rocks in Witwatersrand gold mines carry pyrite crystals of unusual appearance. These crystals, particularly along the dyke margins, show curved and scratched surfaces that cut across crystal faces. The abrasion of the crystals is due to movement of dyke material under pressure. There is some suggestion of surface flow on the abraded surfaces. No deformation or granulation was obtained in laboratory experiments on pyrite crystals. Pressure shadows around the pyrite are described.

PYRITE crystals are frequently observed underground in dyke intrusions in the Witwatersrand gold mines. Fine examples set in the associated rock from a number of the mines were collected for me by mining students of the Witwatersrand Technical College several years ago.

Many of the dykes have been metamorphosed and the original constituents are replaced by quartz or by a chlorite and quartz. Contacts between dyke and sediment may also be post-intrusion fault planes; movement along these faults has further intensified the schistosity of the marginal portions of the dykes which are now dark green chloritic schist with much slickenside.

The pyrite crystals, scattered at random in the body of the intrusions, are more concentrated along the marginal zones (*cf.* Young, 1917, p. 91). They are generally associated with silicification and there are few that are not partly mantled by a thin layer of quartz. The dyke margins are heavily charged with narrow veins and irregular masses of quartz parallel to the contacts. The crystals are not always completely or perfectly developed. Individuals range in size from about 1 mm. across to 5 cm. along the cube edge; crystal aggregates have a similar size range. The striated cube is the dominant form, pyritohedra are less common, while combinations of these, the octahedron, and other forms occur to a minor extent. The curved faces produced by the oscillatory combination of the cube and pyritohedron show remarkably well on the larger specimens. Apart from these observations there is little to warrant

further description of the crystals occurring in the body of the intrusions. Crystals in the marginal zones, on the other hand, often have an unusual appearance. Examples of such pyrite porphyroblasts in dark green



FIGS. 1 AND 2.

FIG. 1 (*top*). Cluster of abraded pyrite crystals, City Deep mine. Abraded surfaces were cut on the left-hand side of the crystals. Although the crystals lie in different orientations, the general scratch direction is the same. Note the fractures and the appearance of a 'burr' on the central crystal.

FIG. 2 (*bottom*). Abraded surfaces on pyrite crystals, City Deep mine. The scratches have the same general direction. The 'protected' portions of the crystals face the top, while the schist is considered to have moved over the crystals from the bottom of the photograph.

schistose rock from two localities on the City Deep mine were considered worthy of closer examination.

The dykes were observed to cut obliquely through the conglomerates, quartzites, and chloritic schists. The pyrite crystals lie either entirely within the dark green schistose dyke or at the contact between vein quartz layers and sediment or dyke. In the latter type of occurrence the crystals have grown on the vein quartz and project into the softer rock.

FIG. 3. Curved and finely scratched surface cut on pyrite crystal, City Deep mine.

Small crystals are also found in the vein quartz, grit, or chloritic schist immediately adjacent to the dyke.

When the enclosing dyke material is carefully removed, two types of surface are observed on the crystals: dull, stained faces that are easily recognized as cubic or pyritohedral, and bright polished surfaces that cannot be referred to simple crystal forms. These bright surfaces are strikingly curved, scratched, and finely pitted (figs. 1 and 2). Close inspection shows that they are not the normal curved faces common in pyrite, but surfaces that cut across original crystal faces (fig. 3). The fine scratches cut across the natural striae and have a common orientation on each surface, although some surfaces may have other sets of scratches superimposed upon those of the dominant direction (fig. 4). Fractures have also developed at right angles to the scratches. It is clear that these curved and scratched surfaces are due to abrasion of the pyrite crystals from which amounts up to several millimetres thick have been removed (fig. 5).

Conspicuous coarse grooves and scratches on the contact surfaces of

FIG. 4. Scratches cutting across natural striae of the cube face, pyrite crystal, City Deep mine.

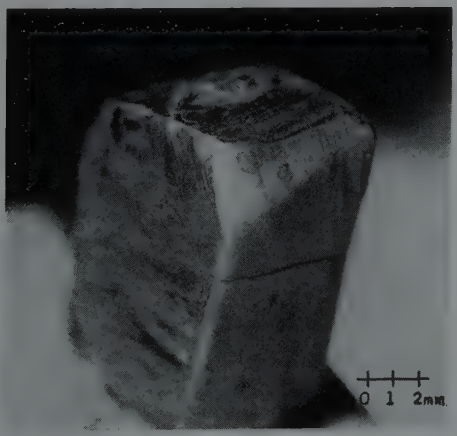


FIG. 5. Abraded coign, pyrite crystal, City Deep mine.

the schistose dyke and vein quartz follow the same general direction as the scratches on the abraded crystals. This direction is slightly modified on crystal aggregates where adjacent faces of individuals form V-shaped

or angular depressions. The amount of abrasion seems to be determined by the orientation of the crystals in the rock (fig. 1). Scattered crystals that have grown in random orientation in both vein quartz and schistose dyke show clearly that abrasion has been effected in one general direction only.

During faulting or metasomatic-metamorphic changes, therefore, only those parts of the crystals presented to the moving dyke material were abraded. The other, or 'protected' parts of the crystals are not modified as a rule and retain original crystal faces. Curved surfaces at both ends of some crystals are due perhaps to a reversal of direction of movement of the rock material. The abrasion of crystals projecting from rigid vein quartz into the softer (plastic) dyke rock may be compared with that of the stoss side of the roches moutonnées of glacial origin.

Thin and polished sections of dyke-quartz and dyke-sediment contact zones were cut both parallel to and across the schistosity. Under the microscope the dyke shows a fine-grained association of angular quartz, albite, and flaky chlorite with magnetite cubes, patches of leucoxene (?), and secondary sphene. The chlorite shows pale green pleochroic tints and is probably a pennine; some flakes have a pink to blue pleochroic scheme. Diffuse oblique illumination reveals faint outlines of original felspar laths in the matrix. The thin sections also show clearly that schistosity becomes more marked towards the dyke margins where the rock is a fine-grained true chloritic schist. Scattered quartz laths are conspicuous in the well-defined schistose arrangement; between crossed nicols many give a twin-like extinction, which indicates that they are a replacement of original twinned felspar phenocrysts in a chilled margin. It is well known that underground, metamorphosed dyke rock is similar in appearance to the chloritic schists of sedimentary origin. Metamorphosed dykes, cutting across bedding planes at low angles, and more particularly sills, may be mistaken for altered sediment. The presence of scattered felspar palimpsests (apart from the fine-grained albite), revealed in thin section, should establish the original igneous nature of the schist.

In thin section granulated and detached fragments of pyrite are seen scattered in the rock near those crystals that have curved and abraded surfaces. This feature was recorded earlier by Harker in 1889. Almost all the porphyroblasts are mantled by a fibrous quartz layer of variable thickness. Polished sections show no development of anisotropism nor any other evidence of deformation of the crystals. Etch tests reveal no zone of surface flow, which if it exists may be of sub-microscopic thick-

ness only. Irregular patches of chalcopyrite lie in the schist between pyrite crystals and marginal vein quartz; between crossed nicols the lamellar twinning makes the anisotropy of the chalcopyrite conspicuous.

Other specimens of similar metamorphosed dyke rock containing abraded and scratched pyrite crystals were collected on the Government Gold Areas and the East Rand Proprietary mines. Pyrite-bearing dyke rock of somewhat different appearance came from the Consolidated Main Reef mine; here the very fine-grained soft dyke rock has a biscuit or dark cream colour and looks rather like unglazed porcelain. Specimens from the body of the dyke are heavily charged with pyrite, which has crystallized as the cube, pyritohedron, and less frequently as combinations of pyritohedron and octahedron. The crystals range from 1 to 10 mm. in size and where they have developed close to one another show little distortion or abrasion. Larger crystals, up to $4 \times 3 \times 2$ cm., rather more scattered, have grown in the marginal portions of the dyke. Irregularly curved surfaces are dull rather than brightly polished and are only partially scratched. Thin sections show that the fine groundmass of this rock is completely sericitized, with scattered fine granules of quartz, a little chlorite, and some secondary sphene. The X-ray powder photograph and diffractometer trace[1] of the dyke material indicate that the dominant mineral is a muscovite rather than sericite. There is no marked schistosity except in the contact zone of the dyke, where scattered silicified and sericitized phenocrysts of presumed felspar are also to be seen.

Fringes or mantles of muscovite flakes around the pyrite crystals are similar to those of fibrous quartz associated with pyrite in the City Deep specimens. These structures, called 'pressure shadows', have been described previously by Harker (1889), Pabst (1931), and many other authors. The width of the shadows is more or less uniform around the pyrite crystals in the central portions of all the intrusions (fig. 6). In the marginal zones, however, the pressure shadows extend in the direction of schistosity and they are therefore frequently wedge-shaped with a thickness varying from 0·1 to 2 mm. They are not always completely formed around the pyrite crystals (Young, 1917, p. 42; pl. XI, fig. 4). Pabst's observation, that the shape of the shadows is largely dependent upon the orientation of the pyrite porphyroblasts with respect to the schistosity, is confirmed.

In the City Deep specimens the shadows consist of 'feather' quartz

[1] Kindly taken by the National Physical Laboratory, Pretoria.

with some interspersed chlorite flakes, and the elongated quartz grains are normal to the crystal faces and some of the abraded surfaces. Many of the abraded surfaces are, however, devoid of quartz fringes, although the 'protected' portions of the crystals have a well-developed shadow; a few shadows are distorted. These observations suggest that the pressure shadows were formed over an extended period that commenced

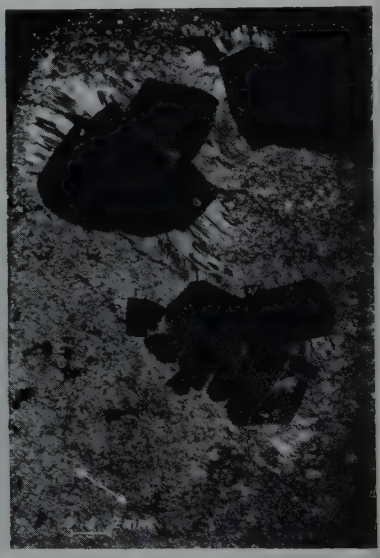


Fig. 6. Fig. 7.

Fig. 6 (*left*). Muscovite pressure shadows around pyrite crystals, Consolidated Main Reef mine. Crossed nicols.

Fig. 7 (*right*). Pyrite crystals in schist, City Deep mine. Fractures in the pyrite crystals are normal to the direction of relative tension (indicated by arrows). The quartz pressure shadows have developed along this direction.

before 'flowage' of the dyke had ceased, and continued, perhaps as a succession of intermittent growths, until well after the abrasion of the pyrite was complete. The relationship between the elongation and the crystallographic directions of the fibrous quartz was investigated on the universal stage according to the method described by Pabst. The results when plotted gave an irregular pattern characteristic of unorientated material and thus support Pabst's conclusion that there is no tendency for any crystallographic direction in the quartz to be parallel to the grain orientation. Cracks in the pyrite are at right angles to the direction of 'stretching' and a perfect example of this relationship is shown in fig. 7.

These cracks are frequently filled with fibrous quartz, which is in continuity with that of the pressure fringes.

The pressure shadows in the Consolidated Main Reef specimens are made up of sericite or muscovite plates with fewer flakes of chlorite and some fibrous quartz grains. Smaller and thinner sericite flakes in the fringes appear to be in haphazard association with the fine quartz particles, but tend to have the greater dimensions normal to the pyrite face. Where the plates of muscovite are larger, and the fringes thicker, the basal plane is parallel to the pyrite face.

Particularly in the City Deep material the high polish on abraded surfaces and what appears to be a burr at the edges of fractures transverse to the scratch directions suggest that there has been some surface flow of the pyrite. As noted above, no deformation was observed in polished section study and it was concluded that if flow had taken place, the layer involved is probably of sub-microscopic thickness.

In general, soft sulphides deform with ease, but the harder minerals are brittle and tend to fracture. Pyrite is regarded as a brittle mineral and it has not been observed to deform as other softer sulphides do. In many deformed rocks pyrite crystals are granulated, 'rounded', or sheared into thin plates. In the examples of abraded crystals here described, however, none of the crystals show shattering or more than slight granulation, though a few small fractures have developed in some crystals, and a little granulated pyrite does occur in the rock near the abraded crystals. The abrasion of the pyrite must have been effected under considerable shearing stress, which might have caused some surface flow.

Dr. Raal kindly took both Laue and oscillation X-ray photographs of some of the abraded and polished surfaces both before and after they had been etched. The Laue reflections before etching are in general seen as multiple spots. After the abraded surfaces had been lightly etched, this multiplicity had largely disappeared. These observations suggest that some surface deformation has taken place. The problem of surface flow and possibly greater deformation of pyrite crystals is worthy of a more intensive X-ray study.

Experimental work on deformation of pyrite was carried out by Adams (1910) and later by Newhouse and Flaherty (1930). Adams embedded pyrite crystals in alum in cylindrical copper tubes, which were subjected to pressures up to 43,000 lb. per sq. in. (see also Buerger, 1928). Newhouse and Flaherty used a modification of Adams's method whereby prepared cylinders of chalcopyrite ore containing pyrite were

fitted tightly into copper tubes. In Adams's experiment on pyrite, the crystal was crushed owing to an unsatisfactory performance of the apparatus. In the later work the pyrite was sheared into thin plates arranged *en echelon* by the movement of the chalcopyrite and the broken fragments had a linear distribution.

As Adams's original experiment was really not satisfactory, it was felt that some further work according to his methods should be done. A number of tests were made using copper tubes having the dimensions given by Adams, in a suitable press in the Department of Mechanical Engineering, Natal University, but the tubes bulged before high pressures could be reached. A further set of experiments, in which tubes of $\frac{1}{8}$ in. wall thickness were used, was then carried out, and pressures of 36 tons per sq. in. were reached. Perfect crystals of simple form, either cube or octahedron, were used. After the experiments, no visible change was observed in the appearance of the faces, nor did measurement show any change of shape or size. Except for a small fracture (which may have been there originally) in one crystal, none of the cubes showed any disintegration after being subjected to pressures reaching 36 tons per sq. in. in successive runs. One octahedron taken to 35 tons per sq. in. developed a clean fracture along a plane parallel to the octahedral face. These experiments show that pyrite does not granulate or shear as a rule, over the range of pressure so far investigated by this method.

There might also be some relationship between temperature and the development of surface flow; the possibility of pyrite yielding under shearing stress at elevated temperatures created during abrasion might be considered.

The events that produced the features of the dykes and the pyrite crystals described in this paper were probably as follows:

Dynamic metamorphism attendant upon folding of the Witwatersrand sediments affected the early minor hypabyssal intrusions. Basic dykes such as those in the City Deep mine, and others intermediate to acidic in composition of which the Consolidated Main Reef occurrence may be representative, were altered to chlorite–quartz–albite or sericite–chlorite–quartz schists. Silica introduced along the dyke contacts and into marginal fractures formed irregular masses and thin vein-like bodies of quartz. Silicification then continued over a long period and may well have been intermittent. Sulphide entered and crystallized as pyrite throughout the body of the intrusions and particularly along the dyke–sediment contacts, which were now highly charged with quartz. The pyrite crystals clearly transect the schistosity; their perfect crystal

lization obscures the nature of any mineral they may have replaced and they are therefore typical automorphic replacements. Continued slow movement pulled schist from the sides of the pyrite crystals and the openings thus developed filled up with quartz or silicates as pressure shadows.

This movement along dyke contacts, which had now become fault planes, produced intense slickensides on the quartz layers. The pyrite porphyroblasts, formed partly in schist and partly in quartz, were held firmly by the latter, and abraded probably by quartz granules in the schist, which under intense shearing stress flowed over and around them. Those portions of the crystals projecting into the schist were ground down with removal of coigns and crystal edges and the development of highly polished, curved, and scratched surfaces. There is no pressure shadow around most of the abraded surfaces, although a shadow is still present on 'protected' portions of the crystals. The presence of pressure shadows around some curved surfaces indicates that shadow growth continued after abrasion of the pyrite. Aggregates of pyrite crystals in the marginal schist, but not anchored in vein quartz, are surrounded by distorted pressure shadows. Clearly there was movement of the matrix during the period of formation of these shadows.

Towards the end of the period with which we are concerned, small amounts of later pyrite and chalcopyrite replaced quartz along the contact of schist and sediment. The twinning of the chalcopyrite suggests that pressure effects had not yet ceased.

Careful search should bring to light many more occurrences of abraded pyrite similar to those described in this paper in the mines of the Witwatersrand and adjacent areas.

Acknowledgements. I am grateful to Prof. F. J. Turner for supplying a specimen of the Calaveras pyrite-bearing slate described by Pabst. I am indebted to Dr. J. N. van Niekerk of the National Physical Laboratory, Pretoria, and to Dr. J. F. H. Custers and Dr. Raal of the Diamond Research Laboratory, Johannesburg, for the X-ray data quoted in the paper. Thanks are due to my colleague, Mr. P. J. Kramer of the Mechanical Engineering Department, for assistance in the pressure experiments and to Mr. P. J. Newman of the Department of Architecture who took the photographs for figs. 1 and 3.

References.

Adams (F. D.), 1910. Journ. Geol., Chicago, vol. 18, p. 489.
Buerger (M. J.), 1928. Amer. Min., vol. 13, pp. 1 and 35.
Harker (A.), 1889. Geol. Mag., new ser., decade 3, vol. 6, p. 396.
Newhouse (W. H.) and Flaherty (G. F.), 1930. Econ. Geol., vol. 25, p. 600.
Pabst (A.), 1931. Amer. Min., vol. 16, p. 55.
Young (R. B.), 1917. The Banket. London.

An unusual cassiterite paragenesis and its genetic implications.

By L. J. Lawrence, Ph.D., B.Sc.

New South Wales University of Technology, Sydney, N.S.W.

[Communicated by Professor S. J. Shand; taken as read 24 January 1957.]

Summary. In the Torrington district of New South Wales the cassiterite occurs almost entirely in hydrothermal veins, with galena, blende, quartz, and chlorite; sometimes it replaces crinoid stems and gastropods. In the Madman vein, however, the cassiterite is associated with adularia, both minerals encrusting quartz. These observations suggest that the tin came in as alkali stannate solutions.

THE specimens described in this paper were obtained from the Torrington tin-mining field 350 miles north of Sydney, in the New England district of New South Wales. For many years this region was the largest producer of tin and tungsten ores in Australia.

Mineralization within the region is related to the closing stages of a differentiated suite of plutonic rocks of epi-Permian age intrusive into Permian sediments and volcanics.

Early stages of mineralization. Two main stages of mineralization may be identified—a high-temperature stage and a relatively low-temperature stage. The high-temperature stage follows what might be termed the normal pattern. Following closely upon the consolidation of the last of the differentiated plutonites—a biotite-granite—pegmatites of both simple and complex mineralogy were developed. The complex pegmatites consist of oligoclase, perthite, biotite, quartz, and beryl, together with a wide range of ore minerals including monazite, arsenopyrite, chalcopyrite, smaltite, safflorite, bismuth, bismuthinite, and large amounts of ferberite for which the Torrington pegmatites are renowned. The gangue minerals, which include fluorite, topaz, and tourmaline, indicate mineralization within a strongly acidic environment.

The pegmatites are closely associated both in space and time with areas of quartz-topaz greisen containing large tonnages of ferberite, together with smaller amounts of tourmaline and fluorite. Here again acidic conditions are manifest.

In a region renowned for its cassiterite production it is remarkable that this mineral has never been observed in the quartz-topaz greisen

and occurred merely as an accessory in only two or three of some twenty ore-producing pegmatites.

Hydrothermal tin veins. A post-magmatic stage of ore deposition within the Torrington region was structurally controlled by a series of shear fractures developed some time after the pegmatite-greisen stage. The shear fractures are uniform in strike throughout the entire region and are of undoubted tectonic (orogenic) origin; they traverse both granite and sediments. When contained in the granite the walls adjacent to the shear are strongly chloritized; the chlorite appears to be hypogene as unaltered biotite is sometimes seen in the chlorite-metasomatized granite walls.

It is within these chloritized zones that the shear planes are situated. Galena, resin-coloured blende, and large amounts of cassiterite occur in a gangue of quartz and colloidal chlorite. A colloform texture has been noted on occasions. Precipitation from hydrothermal solutions of a slightly alkaline character may be postulated.

A significant feature was observed in the Hartz section of the New England lode system. This was the presence of a cross-course, acutely angled with respect to the main lode, containing smoky quartz crystals with copious inclusions of slender tourmaline crystals. Tourmaline crystals also occurred investing the quartz. This cross-course, formed apparently earlier than the main lode which transects it, was well prospected for cassiterite but failed to yield even a trace of that mineral which, in a gangue of quartz and chlorite, was abundant in the main lode.

Cassiterite–adularia vein. Among the many cassiterite veins and lodes of the region is one (the Madman vein) that appears to be unique.

This vein, having the same strike as the other hydrothermal veins and lodes, cuts through kaolinized granite near its contact with the adjacent sediments. It was barren of ore over most of its length; the small amount of cassiterite extracted from the vein occurred in vughs lined with well-formed quartz crystals tinted green by inclusions of colloidal chlorite and reminiscent of the Alpine type. Fig. 1 shows a typical specimen: the quartz is invested by small black cassiterite crystals intimately associated with adularia felspar; both the cassiterite and the adularia are loosely adhering and can be broken from the quartz with comparative ease leaving a clean smooth face of quartz; there has been no corrosion of the quartz and neither the cassiterite nor the adularia has penetrated it during their growth.

Three separate samples of adularia were crushed and examined under

high magnification. They were perfectly free from inclusions or other forms of contamination. Spectrographic analyses were made of each sample giving consistent results as follows: Sn and Pb, trace; Fe and Mg, faint trace; Ca, absent. Each of the nine diagnostic spectral lines of Sn was present in the spectrogram.

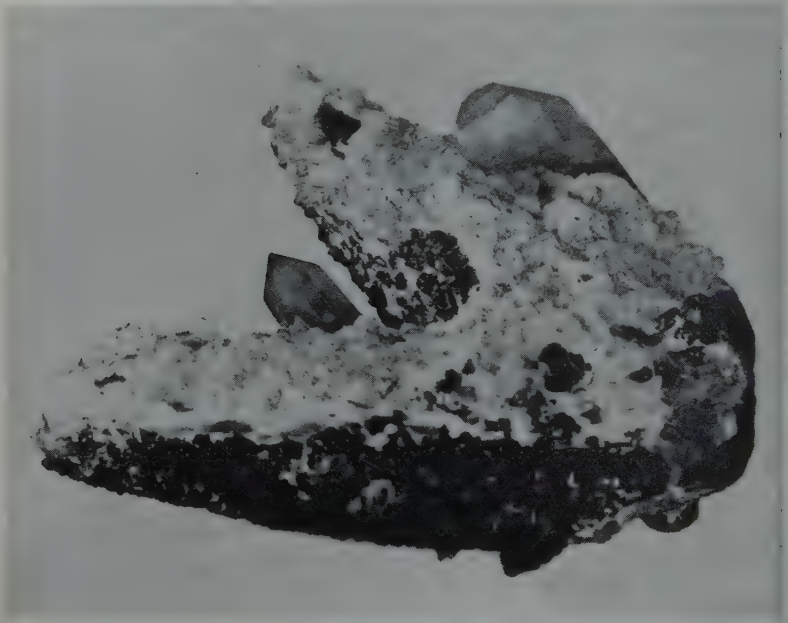


FIG. 1. Quartz crystals loosely invested by black cassiterite crystals and crystals of adularia (white). The Madman tin vein, Torrington, New South Wales. $\times\frac{2}{3}$. This specimen has been presented to the British Museum (B.M. 1957,1).

Fragments of adularia from the figured specimen were examined optically by Mr. P. M. Game, and a partial microchemical analysis was made by Mr. D. I. Bothwell: $\gamma(=[010])$ 1·523, α:[100] 5 to 7°, $2V_\alpha$ 57½°; cleavage (001) perfect, (010) very difficult; K_2O 16·9 %, Na_2O 0·7 %.

Discussion. It has already been suggested (p. 403) that in passing from the pegmatite-greisen stage of mineralization to the shear fissure stage the ore-bearing fluids changed in pH from distinctly acid to somewhat alkaline. The great bulk of cassiterite from the Torrington district thus appears to have been precipitated from somewhat alkaline hydrothermal solutions at moderate temperatures. The conditions of formation of these veins and lodes may be similar to the tin-chlorite veins of

Sungei Lembing, Malaya, which F. H. Fitch[1] suggests were formed at 'relatively low temperatures'.

The intimate association of cassiterite with adularia in one of the veins recalls experiments by F. Gordon Smith of Toronto. He showed[2] that tin could be transported as a sodium or potassium stannate and that cassiterite could be precipitated from such a solution, the best results being obtained at low temperatures.

The adularia of the Madman vein affords further evidence of the alkalinity of the solutions which deposited the associated cassiterite. Detection of Sn in the adularia may indicate a common lineage for the cassiterite and the adularia as follows:

$$K_2Sn(OH)_6 \rightarrow 2KOH + SnO_2 + 2H_2O.$$

The potash so liberated could combine with kaolin and silica to form adularia:

$$2KOH + 2H_2O.Al_2O_3.2SiO_2 + 4SiO_2 \rightarrow 2KAlSi_3O_8 + 3H_2O.$$

Kaolin, it will be noted, is prominent in the granite adjacent to the vein.

Such low-temperature reactions would be compatible with two other mineralogical phenomena recorded from this district. The first of these was the occurrence of cassiterite with zeolites in one of the veins (The Stilbite lode). T. W. E. David[3] records the occurrence thus: 'veinstuff quartz, felspar, and a variety of red stilbite, resembling heulandite. A shoot of tin-stone in heulandite from one to three feet wide and four feet deep was followed down from the surface to a depth of twenty feet for a horizontal distance of nine yards, producing three tons of ore.'

The second is that of the complete replacement of crinoid stems and gastropods by cassiterite with the perfect preservation of both internal and external detail; see fig. 2, and compare L. J. Lawrence.[4]

The cassiterite deposits of the Torrington district appear to have been formed over a wide range of temperature and other environmental conditions. In the case of the fossil replacements it is not unreasonable to postulate the intermingling of hypogene alkali stannate solutions with circulating groundwater. Such a composite solution, moving through fractures and joints in the sediments, would find a ready repository for

[1] Trans. Inst. Min. Met., 1948, vol. 57, p. 195.

[2] Econ. Geol., 1947, vol. 42, p. 251.

[3] The Vegetable Creek tinfield, New South Wales Department of Mines, 1887, p. 116.

[4] Proc. Roy. Soc. N.S.W., 1952, vol. 86, p. 119.

its stannate content in the easily replaceable calcium carbonate of the crinoid stems and gastropods.

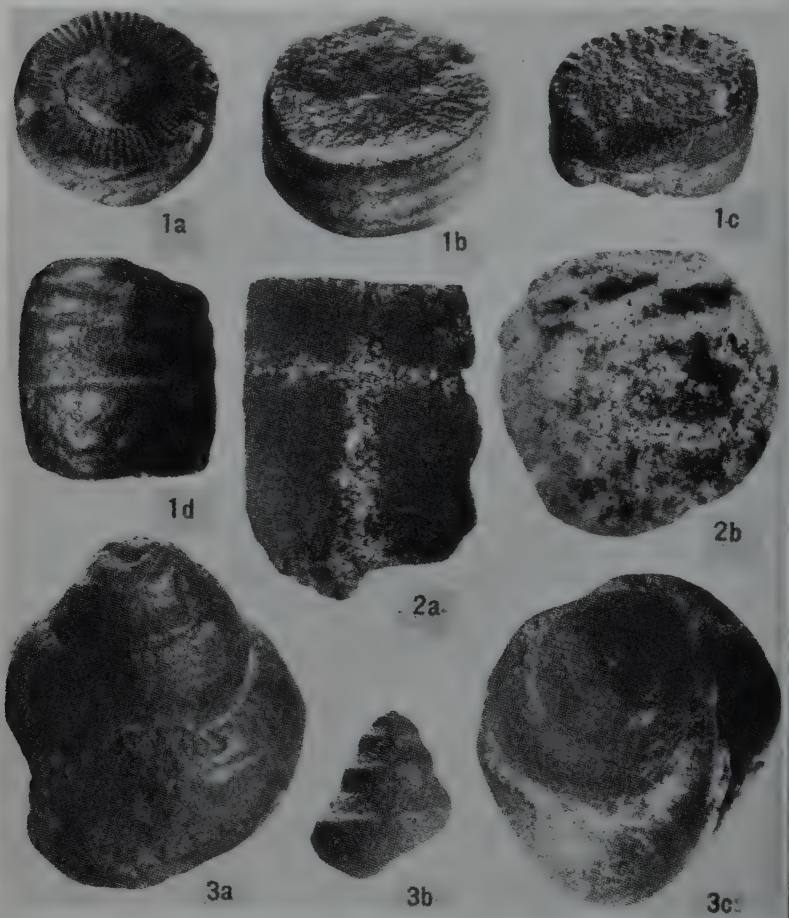


FIG. 2. Crinoid stems and gastropods completely replaced by cassiterite, Emmaville–Torrington district, New South Wales: 1*a*, 1*b*, 1*c*, 1*d* crinoid stems showing preservation of external structure. ×2. 2*a*, 2*b* longitudinal and transverse thin sections showing preservation of internal structure (ordinary light, ×10). 3*a*, 3*b*, 3*c* *Ptycomphalina morrisiana* showing preservation of external detail. ×2.

Acknowledgements. The author wishes to record his thanks to Prof. S. J. Shand and to Prof. F. Gordon Smith for their comments on some of the views herein expressed.

The nature of carphosiderite and allied basic sulphates of iron.

By A. A. Moss, B.Sc., Ph.D., F.S.A.
Department of Mineralogy, British Museum (Natural History).

[Read 24 January 1957.]

Summary. The composition of carphosiderite has been given[1] as

$$H_2O.Fe_3(SO_4)_2(OH)_5H_2O$$

and like the jarosites is characterized by a ferric iron to sulphate ratio of 3:2. It is significant not only that this formula was worked out on artificial material but also that none of the analyses so far made supports it. The present investigation shows that there is little or no evidence for the existence of a mineral with the above composition and that carphosiderites are in reality either jarosite or natrojarosite. It has long been thought that certain other minerals, namely borgströmite, utahite, cyprusite, pastréite, raimondite, apatelite, and planoferrite, were similar to, if not identical with, carphosiderite and six of these are listed with carphosiderite in Dana, Syst. Min., 7th edn. These minerals with the exception of planoferrite and the possible exception of apatelite are also jarosite or natrojarosite.

CARPHOSIDERITE was reported in 1827 by A. Breithaupt[2] who wrote that the mineral occurred in mica-schist on the coast of Labrador, but that the exact locality was unknown to him. In Dana[3] the 'original' carphosiderite is said to come from the Upernivik District, Langø, Greenland. The fact of the matter is, of course, that no one knows where the type material came from, and Breithaupt introduced further complications when he reported, on the results of a qualitative chemical examination by E. Harkort, that the mineral was a basic iron phosphate, although it is clear from the account of the experiments made that the mineral was in fact a sulphate. The first analysis of a mineral supposed to be the type material was published by A. Pisani.[4] The mineral was contaminated by 9 % of gypsum and 10·78 % of sand, and after allowance had been made for these the composition was given as Fe_2O_3 49·88, SO_3 31·82, H_2O 18·30 %. Then, as now, analyses were frequently quoted without even the briefest description of the methods used to determine the constituents, but there can be little doubt that

[1] S. B. Hendricks, Amer. Min., 1937, vol. 22, p. 780 [M.A. 7–87].
[2] Journ. Chem. Phys. (Schweigger), 1827, vol. 50, p. 314.
[3] Syst. Min., 7th edn., vol. 2, p. 566.
[4] Compt. Rend. Acad. Sci. Paris, 1864, vol. 58, p. 242.

the water content of this mineral was determined by difference. This is not surprising since an accurate determination of this constituent is not an easy matter owing to the ease with which these basic sulphates decompose on heating, releasing in the process not only water but sulphur trioxide as well. The second occurrence of carphosiderite was reported by A. Lacroix[1] from St. Léger, Mâcon, the analysis of which was given as Fe_2O_3 48·5, P_2O_5 2·72, SO_3 30·18, H_2O 18·48 %. Here again the water was taken by difference since an analysis of this specimen (see later) kindly supplied to me by Prof. J. Orcel gave the following figures: Fe_2O_3 48·8, P_2O_5 0·6, SO_3 30·6, Na_2O 1·3, K_2O 6·9, H_2O 10·8 %. It will be seen that, although there is reasonable agreement between the two analyses in the proportions of Fe_2O_3 and SO_3, part of that ascribed to water is made up of alkalis. The mineral is in fact jarosite. Lacroix realized his mistake some years later[2] and having learnt that this mineral contained alkalis also came to the conclusion that it was jarosite.

Borgströmite. This mineral from Otravaara, Finland, was first described by M. Saxen[3] in 1923. From the description of his experiments it is evident that alkalis were not looked for. Saxen gives the analyses of two specimens, an impure borgströmite containing limonite and a pure specimen to which, on the basis of his analytical results (Fe_2O_3 51·83, SO_3 28·73, H_2O 19·44 %), he ascribes the formula[4]

$$3Fe_2O_3.4SO_3.9H_2O.$$

This material was later analysed by another author and found to contain 6 % K_2O and accepted by Saxen to be jarosite.[5] His contention that the original impure material, none of which is now accessible, is indeed a new mineral, borgströmite, cannot be accepted in view of the fact that, as in the second analysis, no search was made for alkalis. As will be seen later, a specimen of borgströmite from the type locality analysed during the course of the present investigation proved to be a mixture of jarosite and limonite.

Utahite. A. Arzruni and A. Damour[6] first described this mineral from Eureka Hill mine, Tintic, Utah, and found it to have the following composition: Fe_2O_3 58·82, As_2O_3 3·19, SO_3 28·45, H_2O 9·35 %. Damour, who carried out the analysis, gave a brief account of his methods, from

[1] Bull. Soc. franç. Min., 1887, vol. 10, p. 142.
[2] Min. France, 1910, vol. 4, p. 145.
[3] Bull. Comm. Géol. Finlande, 1923, vol. 11, no. 65, p. 50.
[4] This is the formula for carphosiderite.
[5] M. Saksela [Saxen], ibid., 1952, vol. 26, no. 157, p. 28 [M.A. **12**–179].
[6] Bull. Soc. Min. France, 1884, vol. 7, p. 126.

which it is evident that he determined the water directly, but that, since he performed the rest of the analysis after fusion with potassium carbonate, he did not search for alkalis. A specimen in the British Museum from the same locality proved to be natrojarosite.

Cyprusite. This name was given by P. F. Reinsch[1] to a yellow earthy mineral found by him in Cyprus. Material was collected from the same spot and reported on by Deby[2] two years later. The analysis of the latter material, carried out by H. Fulton, gave, after allowing for some 17 % of insoluble matter (mainly diatoms), Fe_2O_3 49·68, Al_2O_3 3·89, SO_3 35·34, H_2O 11·06 %, figures which differ somewhat from those obtained by Reinsch, but to which Deby nevertheless gave the name cyprusite, believing presumably that Reinsch's analysis was unreliable.[3] This material of Deby is in the British Museum and has been shown on analysis to consist almost entirely of natrojarosite.

Pastréite. The history of this mineral is most unsatisfactory. It was collected at Saint Félix-de-Pallières (Gard), by a Dr. Normann, who named it after President Pastré in Marseilles and *then* sent it to Prof. C. Bergemann in Bonn for examination. Bergemann was of the opinion that it was a decomposition product of varying composition and that it would be unsafe to regard it as a new mineral.[4] In spite of this the name pastréite found its way into the textbooks and has since remained there, although L. Azema[5] has shown that a mineral collected from the type locality by Lacroix and thought to be the pastréite of Normann has, in reality, the same composition as jarosite.

Raimondite and *planoferrite.* It has not been possible to obtain either of these minerals. The claim of raimondite to be a mineral rests on an analysis carried out on behalf of A. Breithaupt by Dr. Ruhe some 90 years ago.[6] The results were given as Fe_2O_3 46·52 and 46·65, SO_3 36·08 and 34·99, H_2O 17·40 and 18·36 %. These figures do not correspond to any simple formula, and may well be wrong; furthermore, the description of the microscopic appearance of the mineral suggests that here again we are dealing with jarosite or natrojarosite.

It has been suggested that planoferrite is also carphosiderite. This

[1] Proc. Roy. Soc., 1882, vol. 33, p. 119.

[2] Journ. Roy. Microscop. Soc., 1884, ser. [2], vol. 4, pt. 1, p. 186.

[3] Rheinsch's analysis was given as oxide of iron ($+Al_2O_3$) 51·5, sulphuric acid 21·5, insoluble siliceous substance 25·0, hygroscopic water 2 %.

[4] C. Bergemann, Verhandl. nat. Ver. Rheinland, 1866, vol. 23, Sitzungsber. niederrheinisch. Gesell. (Bonn), p. 17.

[5] Bull. Soc. franç. Min., 1910, vol. 33, p. 130.

[6] Berg. hütten. Zeit., 1866, vol. 25, p. 149.

mineral was described by L. Darapsky[1] and sent by him to Munich, where it was many years later destroyed during the bombing of that town; it is, however, stated to be soluble in water by which it is subsequently hydrolysed, and is therefore undoubtedly a hydrated ferric sulphate.

Experimental work.

All specimens in the British Museum collection labelled 'carphosiderite', including a recent one from Boolcoomatta, South Australia, proved to be either jarosite or natrojarosite. The whereabouts of the type material not being known, an analysis was made of Lacroix's St. Léger material, supplied by Prof. J. Orcel, of the Musée d'Histoire Naturelle, Paris. Analyses were also made of borgströmite and utahite from the type localities, and of Deby's cyprusite. The X-ray patterns of these minerals showed that they are properly classified as jarosites.

The iron content was determined by precipitation as hydroxide and checked absorbtiometrically (sulphosalicylic acid complex); phosphate also was estimated absorbtiometrically (molybdovanado complex). Sulphate was precipitated as barium sulphate after removal of iron and ammonium salts. The alkalis were determined by the flame photometer after decomposition of the mineral with sulphuric and hydrofluoric acids followed by removal of ferric hydroxide by careful addition of ammonia. F. A. Gooch's method[2] was used to estimate the water content. The results are given in table I, together with the atomic proportions calculated on the basis $(S,P)O_4 = 2$.

Table I. New analyses of 'carphosiderite' and allied minerals.

	A.	B.	C.	D.		A.′	B.′	C.′	D.′
Insoluble (HCl)	0·7	1·1	0·5	1·5					
H_2O-*	nil	1·1	<0·05	0·2					
H_2O+*	10·8	12·6	10·7	11·1	OH	6·1	11·8	6·0	6·2
SO_3	30·6	18·9	31·7	31·8	SO_4 }				
P_2O_5	0·6	nil	nil	tr.	PO_4 }	2	2	2	2
Fe_2O_3	48·8	61·2	51·0	49·1	Fe	3·1	6·5	3·2	3·1
Na_2O	1·3	0·4	5·8	5·4	Na	0·22	0·11	0·95	0·87
K_2O	6·9	4·8	0·6	1·2	K	0·75	0·86	0·06	0·13
	99·7	100·1	100·3	100·3	Na+K	0·97	0·97	1·01	1·00

A. Carphosiderite, St. Léger, Mâcon, France. B.M. 1956,353.

B. Borgströmite, Otravaara, Finland. B.M. 1923,406.

C. Utahite, Eureka mine, Tintic, Utah, U.S.A. B.M. 82743.

D. Cyprusite, Kynussa, Cyprus (35° N., 32° 30′ E.) B.M. 67210.

A′–D′. Atomic proportions recalculated to a basis $(S,P)O_4 = 2$.

* H_2O- below and H_2O+ above 105° C.

[1] Zeits. Kryst. Min., 1898, vol. 29, p. 213.

[2] Journ. Amer. Chem. Soc., 1880, vol. 2, p. 247.

Discussion. It will be seen from the table that the ratio of alkalis to SO_4 is in every case near 1:2 as it should be in a jarosite, and that the iron and hydroxyl proportions in A, C, and D are also in agreement with the accepted formula for a jarosite, $(Na,K)Fe_3(SO_4)_2(OH)_6$. The relative proportions of iron and hydroxyl in B show simply that borgströmite is a mixture of jarosite and limonite,[1] the presence of the latter having been recognized by Saxen in his first paper[2] (1923). It can also be seen from the table that carphosiderite from St. Léger is jarosite, whereas utahite and cyprusite are natrojarosite. There exists no evidence for a mineral of the composition $H_2O.Fe_3(SO_4)_2(OH)_5H_2O$, although Posnjak and Merwin have prepared a compound of such a composition artificially.[3] One of the important properties of these basic alkali ferric sulphates and all minerals previously described as carphosiderite, &c., is their insolubility in water. In the part of their paper that deals with 'carphosiderite' Posnjak and Merwin make no mention of its insolubility; in fact, in their description of their analytical methods they state that 'the weighed samples in most cases were dissolved in a suitable amount of water and a sufficient amount of the solution taken for analysis'. It is not possible, therefore, to deduce whether this artificial 'carphosiderite' is soluble or insoluble in water, although if it were even partly soluble, this fact would be evidence for the difference between the artificial product and the mineral that has so long gone under this name.

Finally a word about synonyms. Except in mineralogy, it has been customary to regard a synonym as a word identical in meaning with that of another known word. It is true that this custom has not always been ignored by mineralogists and some genuine synonyms have been incorporated in their literature. For example, the words sphalerite and blende, being in effect Greek and German renderings of the same idea, can be accepted as synonyms for cubic zinc sulphide without any misgiving, but the retention of, say, the carphosiderite mineral names as synonyms for jarosite is indefensible. In this instance these names have been invented by mineralogists only too eager to discover new minerals, and have, in fact, been introduced into the literature by false pretences, in so far as their compositions have been misrepresented, through errors or oversights in the analyses. We can indeed describe the names of the minerals forming the subject of this paper in the words of a writer[4] long

[1] From X-ray data, this was shown to be goethite.

[2] Loc. cit.

[3] E. Posnjak and H. E. Merwin, Journ. Amer. Chem. Soc., 1922, vol. 44, p. 1976 [M.A. 2–21].

[4] T. A. R[eadwin], Chem. News, 1875, vol. 31, p. 109.

since dead, namely that they are 'mineralogical orphans, fallen out of the ranks from unknown causes or weakness of constitution. Some of their parents and sponsors have been dead a very long while, and nobody appears to know where many of them came from. I don't care to keep an asylum for them any longer, but wish them to die a natural death, and to be sanitarily buried, or cremated (if preferred) clean out of sight and out of mind.'

The morphology of the Unter-Rupsroth montmorillonite.

(With Plates XIV and XV.)

By H. L. Nixon, M.A. and A. H. Weir, B.A.

Rothamsted Experimental Station, Harpenden.

[Taken as read 24 January 1957.]

Summary. Electron micrographs of Na-saturated Unter-Rupsroth montmorillonite show that many of the individual flakes, which are probably 10 Å. thick, have straight edges meeting in 120° angles. This is evidence in support of the pseudo-hexagonal structure of montmorillonite. Similar pictures were obtained with Li-saturated clay and with 'Calgon'-dispersed material. The usefulness of electron microscopy for the study of clay mineral morphology depends upon the efficiency of dispersion and the details of the mounting techniques rather than the nature of the exchange cation or the particular dispersing agent employed.

THE mineral is a montmorillonite from Unter-Rupsroth in the Rhöngebirge, Germany.[1] It is a product of late hydrothermal alteration, and occurs as a pink material in veins in columnar phonolite, and also as a cavity mineral with calcite, chabazite, natrolite, and analcime in a different variety of the phonolite.

Chemical analysis shows a low iron content (Fe_2O_3 0·43, FeO 0·00, MgO 2·13 %), so that the mineral is an intermediate in the montmorillonite–beidellite series. The X-ray powder patterns are those of a typical well-crystallized montmorillonite,[2] and show (*hk*) bands, a 9·5 Å. basal spacing when heated to 500° C., and up to fourteen orders of the basal 17·7 Å. spacing with a glycerol-treated oriented aggregate. In its natural state the exchange cation is predominantly calcium, and the exchange capacity[3] is 113 milliequivalents per 100 g.

Experimental methods. The natural clay was dispersed by adding one drop of a 5 % solution of sodium hexametaphosphate ('Calgon') to 20 mg. of clay in water. After shaking to complete dispersion the suspension was centrifuged at 10,000 *g* for 10 minutes, the supernatant liquid rejected, and the pellet dispersed in distilled water. If this was not done the micrograph was spoiled by the excess 'Calgon'. Sodium- and

[1] F. Heide, Chemie der Erde, 1927, vol. 3, p. 91. G. Nagelschmidt, Min. Mag., 1938, vol. 25, p. 140.

[2] D. M. C. MacEwan, in X-ray Identification and Structure of Clay Minerals. London, Min. Soc., 1951 (p. 101).

[3] R. Greene-Kelly, Min. Mag., 1955, vol. 30, p. 604.

lithium-saturated clays were prepared by repeated washings with normal chloride solutions followed by alcohol and water mixtures until chloride-free. The clay was finally washed in absolute alcohol, dried, and then dispersed in distilled water.

A glass slide was coated with a suitable spreader, such as 'Teepol R' (Shell Chemicals Ltd.), polished with a soft cloth, and a drop of clay suspension was spread over its surface with a glass rod and allowed to dry as a thin film. The slide was then shadowed with either platinum or palladium and coated with a carbon film.[1] Immediately after removal from the vacuum the composite metal-carbon film bearing the clay particles was floated off on to a water surface, whence it was recovered on electron-microscope specimen grids in the usual way.

Results and discussion. The micrographs are shown as negative prints, in which shadows appear dark and heavy deposits of metal white. The direction of shadowing shown by the arrow in pl. XIV was obtained from the pointed edge of the fold shadows, and the shadowing angle to the clay surface is 7° ($= \tan^{-1} 1/8$). Measurement of the maximum shadow length on the thinnest clay layers gives a layer thickness of 15 ± 5 Å., but if the shadows of the thinnest layers from pls. XIV and XV are compared it will be seen that they differ, even though the angles of shadowing and the magnifications are similar. This is not interpreted as meaning that there are different numbers of layers in different pictures, but rather that a precise calculation of layer thickness is not possible where the thickness of the shadowing metal is as great as or greater than that of the layer itself. It seems fairly certain from this and other work that the thinnest layer seen is 10 Å., or one mica-layer thick.

In pl. XIV most of the cleavage flake edges are ragged and show no relation to crystal symmetry, but there are at least 17 angles or re-entrant angles of $120 \pm 5°$ bounded by straight edges. These are considered to reflect the pseudo-hexagonal symmetry of the mica layers, and to be analogous to the hexagonal mica cleavage flakes seen in hand specimens and thin sections. The existence of these angles and edges is direct evidence in support of the widely accepted structure for montmorillonite,[2] which places it with the mica group of minerals containing sheets of silicon-oxygen tetrahedra with hexagonal symmetry. Similar angles of 120° were first reported by Mathieu-Sicaud *et al.*[3] in electron

[1] D. E. Bradley, Nature, 1953, vol. 171, p. 1076.

[2] D.M.C. MacEwan, loc. cit., p. 87.

[3] A. Mathieu-Sicaud, J. Mering, and I. Perrin-Bonnet, 1951, Bull. Soc. franç. Min. Crist., vol. 74, p. 439.

micrographs from dilute Na-montmorillonite suspensions, but they cannot be seen clearly in the published pictures. In pl. I, facing p. 456 of their paper, they showed a continuous film of material, in which individual flakes, although poorly defined, appear to be similar to montmorillonites from Redhill, Surrey, and from Wyoming. In our experience straight edges and angles of the kind described here are rarely found in these clays.

Other features of interest include the size of the flakes and their folding. The larger flake in pl. XIV is about $3\mu \times 4\mu$, and this is not exceptional for the material. It is appreciably larger than Wyoming bentonite, hitherto regarded as a montmorillonite of large particle size. The height of the folds, obtained from their shadows, varies between about 100 and 200 Å., and is probably the maximum curvature the silicate sheets can maintain. This folding, which is quite common in montmorillonites, must arise from the thinness of the sheets; the ratio of length or breadth to thickness for the large sheets in pl. XIV is 3 or 4μ to 10 Å., a ratio of about 3000 : 1. The analogy with a sheet of paper folded back is enhanced by the tears in the silicate sheet where the fold does not quite reach to the edge of the flake. In the centre of the field two sets of sub-parallel folds give a 'basket' effect, and an overlying flake follows the contours of the folds closely, leaving little or no interstitial space. It is also noticeable that whereas folds with their maximum curvature facing the source of platinum show a bright line caused by an accumulation of metal, those facing the other way show a double shadow effect suggesting a concave surface on the side of lower curvature, towards the centre of the flake.

The second plate is included to illustrate the effect (or rather, lack of effect) of different exchangeable cations on the morphology of the mineral. We have shown that complete dispersion results in flakes one mica-layer thick, and to describe montmorillonites we have reserved the term morphology for descriptions of the shape of these single layers. T. F. Bates[1] mentioned that the shape of particles of montmorillonite depends upon the nature of the dispersing agent, the exchange cation, and the grinding procedure. The inference that Na-saturated montmorillonites have poor particle outlines has not been confirmed in recent work at Rothamsted. On the contrary, micrographs showing the straight edges and well-defined angles illustrated here have also been obtained with the Black Jack mine beidellite and occasionally with Wyoming

[1] Clays and Clay Technology, Calif. Div. Mines, San Francisco, 1955, Bull. 169, p. 130.

bentonite. This is in agreement with a recent note by R. Roy and L. B. Sand,[1] which includes a micrograph of a synthetic Na-beidellite that has clearly outlined lath-shaped particles with straight edges.

To test whether exchanging the cation affects morphology, the micrographs reproduced in pl. XV were taken. No difference can be seen between Li-montmorillonite dispersed in water and the Na material of pl. XIV, or between these and the 'Calgon'-dispersed natural Ca-clay, although it is probable that dispersion with 'Calgon' entailed exchanging Na for Ca. This possibility of exchange also exists with other commonly used dispersing agents, which in addition are much less effective than 'Calgon'. An attempt to disperse the Ca-clay in water using supersonic shaking at 25 kc. failed, and the resulting micrographs showed large aggregates. Similar pictures were obtained with the Li-clay when it was insufficiently dispersed in water, although complete dispersion gave the micrographs shown in pl. XV.

The evidence presented here suggests that the state of dispersion of the material and the technique used for making the electron-microscope mounts of montmorillonite have a major effect on the usefulness of the resulting pictures for studies of particle morphology. In our experience these factors are more important than the nature of the exchangeable cation or the particular dispersing agent employed.

Acknowledgements. We wish to thank Prof. U. Hofmann for supplying the montmorillonite sample from Unter-Rupsroth, Drs. A. Muir and R. Greene-Kelly for helpful criticism, and Mr. R. Woods for technical assistance.

Explanation of Plate XIV.

Electron micrograph of Unter-Rupsroth montmorillonite, negative print. Specimen Na-saturated, water dispersed. Shadowing: platinum at 7° to the clay surface. The arrow indicates the direction of shadowing.

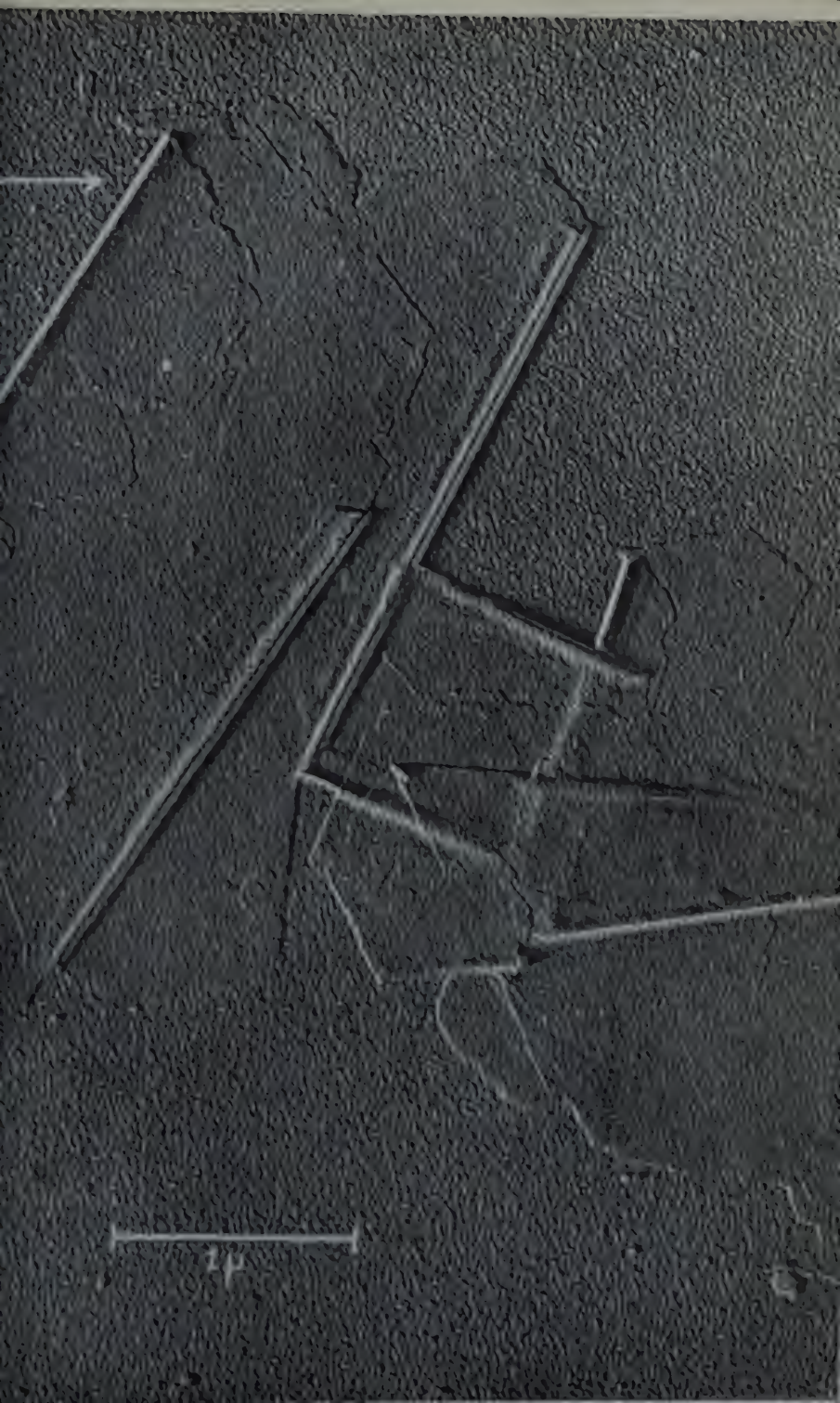
Explanation of Plate XV.

Electron micrographs of Unter-Rupsroth montmorillonite, negative print.

A, *B*. Specimen Li-saturated, water dispersed. Shadowing: platinum at 7° to the clay surface.

C. Specimen natural clay, mainly Ca, Calgon dispersed. Shadowing: palladium at 7° to the clay surface.

[1] Amer. Min., 1956, vol. 41, p. 505


1μ

1μ
A
1μ
B
1μ
C

Heating experiments on amazonite.

By Ivar Oftedal, Ph.D.
Min. Inst., University of Oslo.

[Taken as read 24 January 1957.]

Summary. The rate of decolorization of a Norwegian amazonite was studied at various temperatures: near 500° C. it was almost instantaneous, becoming successively slower with lower temperatures, until at 300° C. no change was visible in 10 hours. It is concluded that the colour is stable indefinitely below about 270° C. and that this is the maximum temperature at which the colour could have appeared.

IT is well known that the green colour of amazonite disappears on heating. Having at my disposal excellent specimens of a very intensely and evenly coloured amazonite (from Tørdal in Telemark, Norway), I have examined the velocity of decolorization at various temperatures. The actual experiments were very kindly carried out for me by Prof. Ivan Th. Rosenqvist, whose laboratory (in Norges geotekniske institutt, Oslo) was already equipped with suitable apparatus. I am also indebted to Dr. Rosenqvist for valuable comments on the results. The heated samples were small cleavage fragments a few millimetres thick, so that they should quickly attain the temperature of the oven. On complete disappearance of the green colour the amazonite is nearly snow white (colourless in thin flakes); therefore, even the slightest remnants of green colour can easily be observed. I would add here that the amazonite has been examined spectrochemically both unheated and after complete decolorization, and that no change in the content of trace elements (essentially Rb, Pb, Tl) could be observed. Sometimes partly white amazonite crystals may be found in the pegmatites; these are also spectrochemically homogeneous.

The data obtained from the heating experiments are as follows:

T, ° C.	t, hrs.	% loss of colour	T, ° C.	t, hrs.	% loss of colour
500	<0·1	100	400	1	85
450	0·5	99	360	5	90
450	0·4	95	300	16	<80
450	0·3	90	270	10	0
400	5·5	99			

It must be remarked that the figures, except those for t, are approximate. The temperature readings may differ by 10° to 20° from the

correct values. The decolorization percentage was determined by a rough colorimetric method, using a liquid whose colour was approximately that of the unheated amazonite; the determinations are very uncertain at low percentages, but fairly safe for percentage decolorizations around 90.

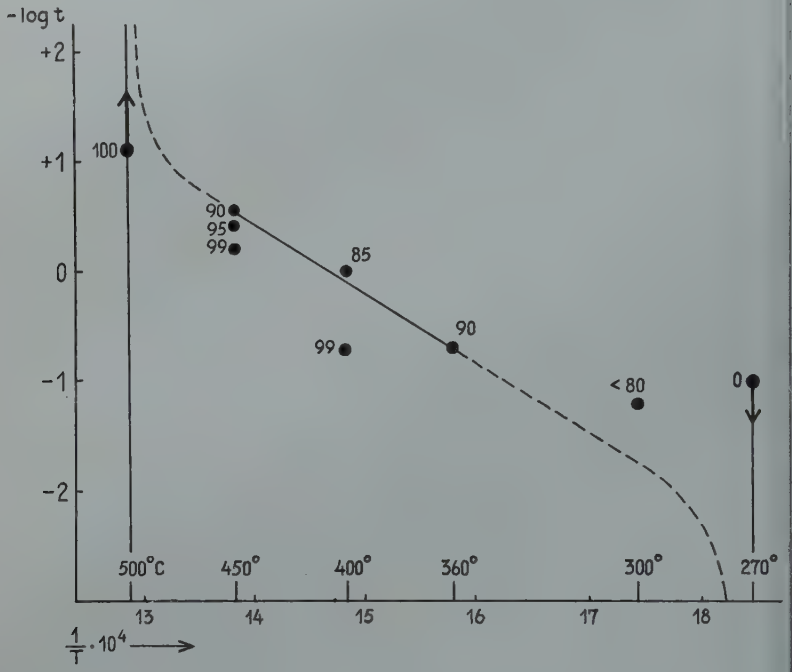


FIG. 1.

The results may be plotted in a diagram (see figure) with $1/T$ (degrees absolute) for abscissa and log $1/t$ (which is proportional to the log of specific rate of decolorization) for ordinate. It is seen that the curve for 90 % decolorization can be drawn fairly safely. The curve is approximately straight in the middle portion, at least from 450° C. to somewhat below 350° C. (The curves for various percentages are expected to be all parallel; it can be seen that the 85 % and 95 % curves will be approximately parallel to the 90 % curve.) Above 450° C. the curve bends upwards and must be supposed to approach a limiting ordinate near 500° C. asymptotically. In the same way it bends downwards somewhere below 300° C.; the limiting ordinate is here probably near 270 ° C. The activation energy of decolorization can be estimated from the slope

of the straight part of the curve. It turns out to be of the same order of magnitude as the activation energies of various diffusion and decomposition processes, about 30 000 cals./mole.

From these observations it seems justified to conclude that the colour of amazonite is due to 'colour centra' in the same way as, for instance, the blue colour sometimes found—and easily developed artificially—in rocksalt. The nature of the colour centra in amazonite is not known. From the above data it is obvious that they were formed at temperatures below 300° C., probably at about 250° C., that is in already crystallized and considerably cooled felspar. This is in accordance with the field observations, which strongly indicate that the green colour originated in connexion with the formation of cleavelandite pegmatite veins in the already existing microcline pegmatite. It is sometimes observed that the green amazonite colour is exceptionally intense along the immediate contact towards a cleavelandite pegmatite vein. The new elements introduced during the formation of the cleavelandite pegmatite were chiefly F, Li, Be, Sn. Fluorine was especially abundant, as shown by the considerable quantities of topaz and lithium micas present in these veins. The colour centra may be due to the action of F on the microcline crystals. Perhaps F ions replace a few of the O ions in the crystals, thus creating the unstable distribution of charges which is supposed to produce this kind of colouring.

Literature on colour centra and defective structures.

Hauffe, K. Reaktionen in und an festen Stoffen. Springer, Berlin, 1955.

Przibram, K. Verfärbung und Lumineszenz. Springer, Wien, 1953.

Both of these books contain numerous references to original papers.

Painite, a new mineral from Mogok, Burma.

By G. F. Claringbull, B.Sc., Ph.D., A. Inst.P.,
and Max H. Hey, M.A., D.Sc.

Department of Mineralogy, British Museum (Natural History)
and
C. J. Payne, B.Sc.

Laboratory of the Diamond, Pearl, and Precious Stone Trade Section
of the London Chamber of Commerce.

[Read 1 November 1956.]

Summary. A singly terminated transparent, deep-garnet-red crystal originally weighing 1·7 g. from a gem gravel from Mogok, Burma, proves to be a new mineral having Al_2O_3 76·2, SiO_2 5·6, B_2O_3 2·2, CaO 15·7, H_2O 0·7, Fe_2O_3 and MnO traces, total 100·4. Sp. gr. 4·01; ω 1·8159, ϵ 1·7875; *H* 8. The hexagonal unit cell has *a* 8·725, *c* 8·46 Å., space group $P6_3$, $P6_3/m$ or $P6_3$ 22, and contains approximately 38 O. The name painite is proposed in honour of A. C. D. Pain who recognized the unusual nature of the crystal.

In 1952 Mr. A. C. D. Pain sent to London a deep-garnet-red crystal weighing 1·7 g. which had been found in one of the small ruby mines near Ohngaing village, Mogok, Upper Burma. The crystal after passing through several hands came for examination to the London Chamber of Commerce Laboratory where its optical properties and density were accurately measured. As it was found impossible to identify the mineral from these constants it was passed to the British Museum Department of Mineralogy for further tests. Subsequent work has shown that the mineral is new to science and it has been named painite after Mr. A. C. D. Pain, the enthusiastic gem collector who first recognized the unusual nature of the crystal, agreed to a portion being sawn from the fractured base for chemical and X-ray work and subsequently presented the crystal to the British Museum (Natural History) where it is registered under the number B.M. 1954,192. The present weight of the crystal is 1·48 g.

X-ray determinations. When an X-ray powder photograph and an arc spectrogram did not provide a solution to the riddle of identification, a single-crystal X-ray examination was carried out on a small fragment of the sawn-off portion by stationary- and moving-film methods. The symmetry was found to be hexagonal and Weissenberg photographs of

zero, 1st, and 2nd layer-lines about [0001] and [10$\bar{1}$0] showed the systematic space-group absence 000l for l odd: the space-group is thus $P6_3$, $P6_3/m$, or $P6_3\,22$.

The cell dimensions were determined from the zero layer of back-reflection rotation photographs indexed by reference to Weissenberg photographs. For the a-axis the high-order reflections of type $hki0$ were plotted against $\sin^2\theta$ and extrapolated to $\sin^2\theta = 1$ but for the c-axis insufficient reflections of suitable spacing were available and the accuracy of the value for the c-spacing is consequently somewhat lower than that for a. The hexagonal cell dimensions are a 8·725±0·005, c 8·46±0·01.

An X-ray powder photograph of painite (fig. 1) has been indexed using these cell dimensions (table I).

Physical properties. The hardness is about 8. The refractive indices determined by the method of minimum deviation on a table spectrometer for sodium light are ω 1·8159, ϵ 1·7875; the mineral is thus uniaxial negative with $\omega-\epsilon$ 0·0284. Pleochroism ranges from ruby red for vibrations parallel to c to pale brownish-orange perpendicular to c.

The density of the whole crystal was first determined by hydrostatic weighing in ethylene dibromide and found to be 4·01±0·01. The crystal contains a number of inclusions, some rounded and others tabular and hexagonal in outline (fig. 5), as well as some feather-like sheets of minute cavities similar to those seen in gem-corundum. In view of the inclusions a second density determination was made on an inclusion-free fragment by flotation in Clerici solution and gave 4·00±0·02.

Morphology. The development of the crystal is shown in the photographs figs. 2 and 3 and the parallel perspective drawing fig. 4; in two-circle coordinates with the normal to c(0001) at $\rho = 0°$ and the normal to a(01$\bar{1}$0) at $\phi = 0°$, the view-points of these figures are: fig. 2, ϕ 90°, ρ 65°; fig. 3, ϕ 300°, ρ 45°; fig. 4, ϕ 257°, ρ 40°. It will be seen that the notably pseudorthorhombic appearance is due to four faces of the form $a\{10\bar{1}0\}$ being well developed and one parallel pair very narrow.

The prism faces $a\{10\bar{1}0\}$, $m\{11\bar{2}0\}$, $k\{12\bar{3}0\}$, and $l\{13\bar{4}0\}$ all give excellent reflections, though some of the faces are very narrow strips. One prism face, seen to the left of fig. 2, is strongly striated, and is an oscillatory combination of $a(1\bar{1}00)$, $k(2\bar{3}10)$, and $l(3\bar{4}10)$. The basal plane c(0001) and the pyramids $o\{11\bar{2}1\}$, $p\{11\bar{2}2\}$, $q\{20\bar{2}1\}$, $r\{10\bar{1}1\}$, and $s\{10\bar{1}2\}$ are matt, with rounded edges, but are sensibly plane and readily identifiable; it is not, however, possible to make measurements with any better accuracy than about 1 to 2°, and the axial ratio is therefore taken from

TABLE I. X-ray powder data for painite.

I.	$d_{obs.}$	$d_{calc.}$	*hkil.*	*I.*	$d_{obs.}$	$d_{calc.}$	*hkil.*
m	7·63	7·56	$10\bar{1}0$	vw	1·389	1·386	$10\bar{1}6$
vs	5·76	5·63	$10\bar{1}1$	vvw	1·377	1·375	$33\bar{6}2$
vvw	4·37	4·36	$11\bar{2}0$	vvw	1·353	1·353	$42\bar{6}2$
vw	4·24	4·23	0002			1·340	$51\bar{6}1$
s	3·70	3·69	$10\bar{1}2$	w	1·340	1·341	$32\bar{5}4$
		3·78	$20\bar{2}0$			1·342	$11\bar{2}6$
m	3·45	3·45	$20\bar{2}1$	vw b	1·318	1·316	$31\bar{4}5$
mw	3·03	3·04	$11\bar{2}2$			1·321	$20\bar{2}6$
m	2·820	2·820	0003	w	1·301	1·300	$41\bar{5}4$
		2·816	$20\bar{2}2$	w	1·292	1·292	$51\bar{6}2$
mw	2·707	2·706	$21\bar{3}0$				$33\bar{6}3$
vw	2·649	2·643	$10\bar{1}3$	w	1·275	1·274	$42\bar{6}3$
vs	2·520	2·518	$30\bar{3}0$	vvw	1·268	1·264	$21\bar{3}6$
s	2·370	2·368	$11\bar{2}3$	mw	1·260	1·260	$40\bar{4}5$
		2·367	$21\bar{3}2$			1·259	$60\bar{6}0$
w	2·260	2·260	$20\bar{2}3$	vvw	1·243	1·242	$43\bar{7}0$
vw	2·182	2·181	$22\bar{4}0$			1·246	$60\bar{6}1$
vw	2·158	2·163	$30\bar{3}2$	mw	1·231	1·230	$50\bar{5}4$
vvw	2·119	2·115	0004			1·229	$30\bar{3}6$
		2·112	$22\bar{4}1$				$43\bar{7}1$
m	2·093	2·095	$31\bar{4}0$			1·211	$32\bar{5}5$
mw	2·036	2·037	$10\bar{1}4$	vw	1·211	1·210	$52\bar{7}0$
		2·034	$31\bar{4}1$			1·209	0007
s	2·008	2·007	$21\bar{3}3$	vw	1·200	1·198	$52\bar{7}1$
vvw	1·975	1·977	$22\bar{4}2$	vvw	1·169	1·170	$31\bar{4}6$
mw	1·904	1·903	$11\bar{2}4$	vvw	1·162	1·163	$52\bar{7}2$
w	1·880	1·878	$30\bar{3}3$			1·159	$20\bar{2}7$
			$31\bar{4}2$	vw	1·152	1·150	$60\bar{6}3$
vw	1·843	1·843	$40\bar{4}1$	vvw	1·142	1·142	$51\bar{6}4$
		1·846	$20\bar{2}4$				$61\bar{7}1$
ms	1·726	1·725	$40\bar{4}2$	vvw	1·139	1·137	$43\bar{7}3$
w	1·699	1·700	$21\bar{3}4$	vvw b	1·132	1·130	$40\bar{4}6$
		1·698	$32\bar{5}1$	w	1·112	1·113	$21\bar{3}7$
mw	1·682	1·681	$31\bar{4}3$	vvw	1·095	1·094	$32\bar{5}6$
vvw	1·651	1·651	$10\bar{1}5$	vw	1·082	1·090	$44\bar{8}0$
		1·649	$41\bar{5}0$	vvw	1·068	1·072	$41\bar{5}6$
mw	1·620	1·620	$30\bar{3}4$	vvw	1·060	1·057	0008
		1·618	$41\bar{5}1$				$22\bar{4}7$
mw	1·603	1·604	$32\bar{5}2$	vw	1·051		
		1·603	$11\bar{2}5$	w	1·048	1·047	$10\bar{1}8$
vw	1·570	1·569	$40\bar{4}3$				$31\bar{4}7$
vvw	1·545	1·545	$20\bar{2}5$	vvw	1·040		
vw	1·520	1·518	$22\bar{4}4$	vw	1·028	1·028	$11\bar{2}8$
vvw	1·476	1·477	$32\bar{5}3$	vw	1·019	1·018	$40\bar{4}7$
m	1·453	1·454	$33\bar{6}0$	w	1·014		
		1·456	$21\bar{3}5$	vvw	1·009		
		1·423	$41\bar{5}3$	vw	1·003		
ms	1·423	1·428	$50\bar{5}2$	vvw	1·000		
			$42\bar{6}0$	vvw	0·992	0·991	$32\bar{5}7$
		1·410	0006				
mw	1·411	1·409	$40\bar{4}4$				
		1·408	$42\bar{6}1$				

the X-ray study ($c:a = 0{\cdot}970 \pm 0{\cdot}002$). From this the angles between the several pyramids and the basal plane were calculated and compared with the observations:

Calc.	o 62° 43′,	p 44° 7′,	q 65° 57′,	r 48° 14′,	s 29° 15′
Obs.	64°	46½°	68°	49½°	30½°

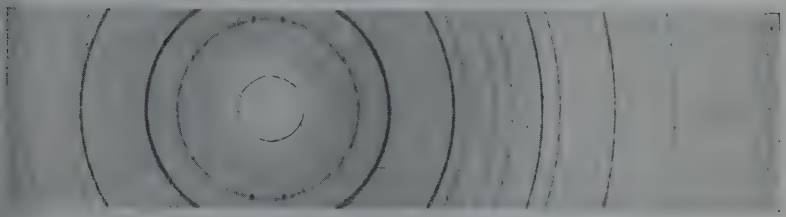


FIG. 1. X-ray powder photograph of painite. 11·46 cm. diameter camera, Cu-Kα radiation.

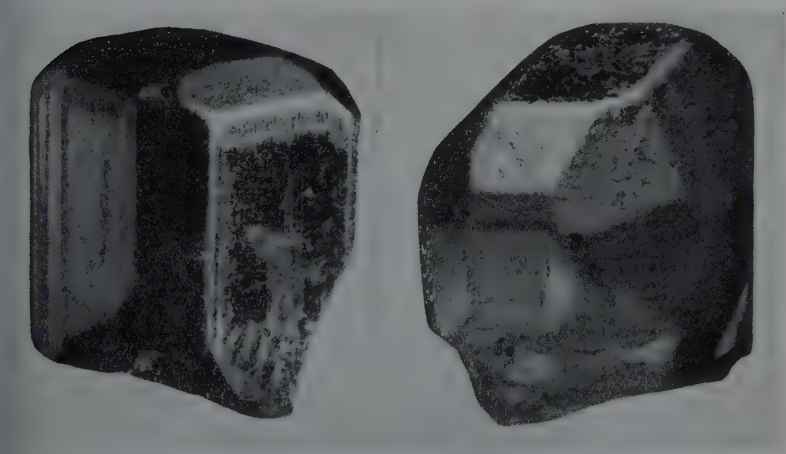


FIG. 2. FIG. 3.

FIGS. 2 and 3. Photographs of the crystal of painite from two viewpoints: fig. 2 (left) about 15° from the normal to $m(2\bar{1}\bar{1}0)$, and fig. 3 (right) nearly normal to $(\bar{1}101)$.

Chemistry. Painite is a highly resistant mineral, insoluble in acids, and only slowly attacked by fusion with sodium carbonate or with sodium pyrosulphate. For the chemical analysis it proved necessary to recover the unattacked material from the first sodium carbonate fusion (1 hour) and repeat the operation. The determination of B_2O_3 was made on a portion of 18 mg., and the remainder of the analysis in duplicate

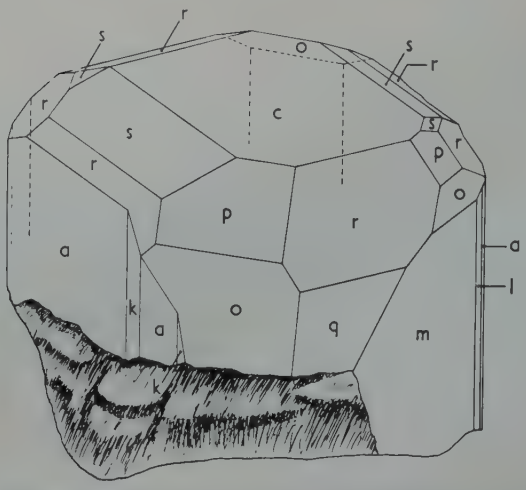


FIG. 4. Parallel perspective drawing of the crystal of painite, from a viewpoint between r ($\bar{1}011$) and p($\bar{2}112$).

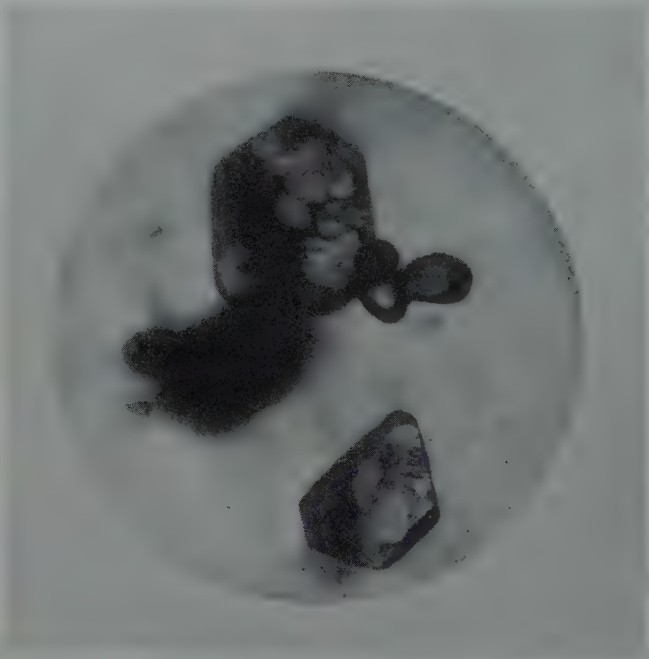


FIG. 5. Photomicrograph through c(0001) of inclusions in painite, some tabular with hexagonal outline and others rounded.

on portions of 38 mg. and 17 mg. The results are shown in table II; the assessed probable errors are based on assumed limits of Al_2O_3 $\pm 0{\cdot}3$ %, SiO_2 $\pm 0{\cdot}5$ %, B_2O_3 $\pm 0{\cdot}3$ %, and CaO $\pm 0{\cdot}2$ %, together with

TABLE II. Chemical analyses and empirical unit-cell contents of painite.

Al_2O_3	76·2	Al	$20{\cdot}20 \pm 0{\cdot}14$	
SiO_2	5·6	Si	$1{\cdot}26 \pm 0{\cdot}11$	Σ (cations)
B_2O_3	2·2	B	$0{\cdot}85 \pm 0{\cdot}12$	$26{\cdot}09 \pm 0{\cdot}22$
CaO	15·7	Ca	$3{\cdot}78 \pm 0{\cdot}05$	
H_2O	0·7	O	$37{\cdot}88 \pm 0{\cdot}22$	
	100·4			

$\pm 0{\cdot}02$ in the density; the probable error of the density determination ($4{\cdot}01 \pm 0{\cdot}01$) was doubled to allow for the inclusions, although a separate determination by flotation on a small fragment free from inclusions gave $4{\cdot}00 \pm 0{\cdot}01$, indicating that these do not affect the density appreciably. The water was assumed to be an impurity adsorbed during grinding, and therefore no correction to the density was made for adsorbed water.

The empirical unit-cell contents clearly indicate an oxygen content of 38, and suggest a cation content Ca_4SiBAl_{20}, but this would only require $37\frac{1}{2}$ oxygen, and it is evident that either the oxygen or the total cations must be a non-integral number.

The nature of painite. Painite appears to be more closely related chemically to compounds of the 'β-alumina' type[1] (e.g. $3CaO.16Al_2O_3$) than to any other compound we have been able to trace. However, the cell-dimensions do not support this affinity. A relationship is suggested by the cell-dimensions to compounds isostructural with $BaAl_2O_4$ (a $5{\cdot}21 \times \sqrt{3} = 9{\cdot}00$; c $8{\cdot}76$)[2] but this must be excluded because the packing density of these is only about two-thirds that of painite. It is evident from the high density, very close to that of corundum, that the oxygen atoms of the structure must be nearly close-packed: but there is no obvious structural relationship either to corundum or to spinel.

We wish to acknowledge the assistance of Miss J. Tolliday, Miss E. Fejer, and Mr. D. Williams with the X-ray determinations.

[1] K. Lagerqvist, S. Wallmark, and A. Westgren, Zeits. anorg. Chem., 1937, vol. 234, p. 12 [M.A. 7–235].

[2] S. Wallmark and A. Westgren, Arkiv Kemi, Min. Geol., 1937, vol. 12B, no. 35 [M.A. 8–366].

SHORT COMMUNICATIONS

A technique for the preparation of thin sections for thermal treatment, together with their remounting.

Detection and analysis of small changes in the optics of crystals after heat treatment can only be obtained with precision by making two sets of determinations, one before and one after heating, upon the same crystals in a thin section. For temperatures above 500° C. ordinary sections made on glass slides are useless. The following method has been devised to allow a thin section to be heated to 1100° C.

The thin section is prepared in the usual manner upon a slide, not of ordinary glass but of transparent, isotropic silica-glass. When covering the thin section with the glass coverslip, the balsam should be slightly 'overcooked' to facilitate subsequent removal.

After measurement of the chosen crystals, the section is prepared for heating. First, the coverslip is removed mechanically with a razor-blade. The section is then placed face upwards across two low supports in a crystallization dish, and sufficient chloroform is added to immerse it. After one hour the balsam cementing the section to the slide should be completely dissolved. The chloroform is then removed with a dropper, great care being taken in order to avoid surface ripples which will fracture the uncemented section.

The slide, with the section now resting freely upon it, is supported on a flat plate of sintered alumina and placed in an oven to be heated under the conditions desired.

When cool, the section is remounted. The slide is given a very low tilt by inserting a thin card under one end. A few drops of a solution of equal quantities, by volume, of Canada balsam and chloroform are made to coalesce at one end of the slide, and allowed to flow down the slide, engulfing the thin section. The slide is now levelled, covered with a watch-glass, and allowed to stand for 48 hours. Evaporation of the chloroform should then have rendered the Canada balsam reasonably hard. The section can be covered in the normal manner with a glass coverslip.

This method can be adapted to deal with sections already prepared on ordinary glass slides. The coverslip should be removed as before. A silica-glass slide is placed on the bottom of a crystallization dish between two glass supports. The thin section is then placed face down-

wards across the two supports so that the thin section is immediately above the surface of the silica-glass, and about 1 mm. from it. The two slides should have their longer axes perpendicular. The arrangement is shown in fig. 1.

Sufficient chloroform is poured into the dish to immerse the upper (glass) slide completely. After about half an hour, solution of the

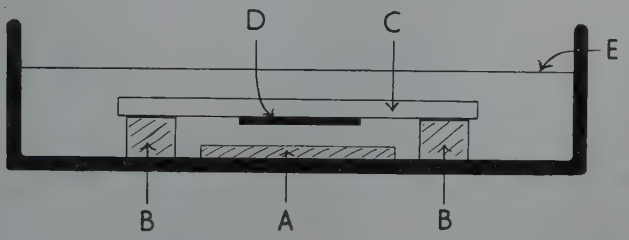


Fig. 1. Diagram, vertical scale exaggerated, showing transfer arrangement. A the Vitreosil slide, B glass supports, C the glass slide, D thin section, E surface of chloroform.

Canada balsam will allow the thin section to become detached from the glass slide, and to fall vertically onto the silica-glass slide. The glass slide is then gently manœuvred to the side and the chloroform removed with a dropper, the rest of the process being the same as that already described.

This method of transference causes the section to be inverted, but providing photomicrographs, upon which the measured crystals can be plotted and replotted, are taken before and after heating, no difficulty should occur in tracing individual crystals.

My thanks are due to Dr. G. F. Claringbull and to Mr. P. M. Game for advice in the preparation of this note.

Dept. of Mineralogy, H. G. Owen
British Museum (Natural History),
London, S.W. 7.

A section-holding chuck for use on high-speed surface-grinding machines.

This note describes an improved section-holding chuck for use on the table of a high-speed surface-grinding machine fitted with a diamond-impregnated grinding wheel. It also suggests modifications in mounting technique, and some measurement limits for this type of grinding.

The chuck. This chuck, built by Mr. E. W. Davies of this Department, holds seven mounted sections for simultaneous grinding, but the number can be varied according to individual needs and size of table (fig. 1). The seven mounts are held by the chuck in the same plane parallel to the axle of the surface-grinding wheel. Each slide is raised and secured

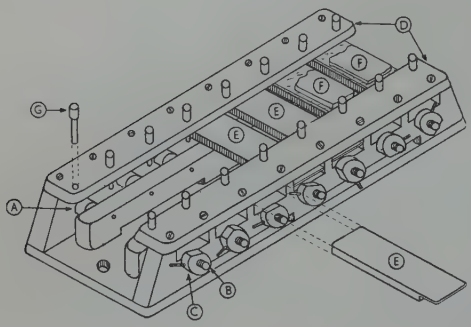


Fig. 1.

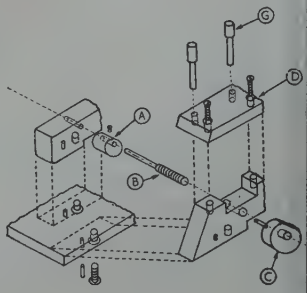


Fig. 2.

Fig. 1. Isometric drawing of the chuck. A, silver-steel cam: B, silver-steel cam screw: C, cam lock-nut: D, clamping bars: E, slide support plate: F, section clamped in grinding position: G, studs.

Fig. 2. Expanded view of the cam mechanism.

against two clamping bars normal to the axle of the wheel. These bars are machined to have their under-surfaces in a common plane parallel to the table of the surface grinder. By this method the upper surface of each slide lies in a common plane (the grinding plane) regardless of inequalities in individual slide thickness. In consequence slides need none of the measurement and pre-grinding to uniform thickness that have been suggested for other clamping methods.

Each slide lies on a thick metal base plate, resting at each end on cams set beneath the clamping bars. These cams are tightened independently and have their own lock-nuts (fig. 2). The system, which is secure and adequate to withstand the strains of high-speed grinding, permits the individual mounting and removal of slides from the side of the chuck: a practice more flexible than serial mounting from the ends of the chuck. If for any reason one of the cams is not secured, the section base plate and the slide will drop out of the grinding plane. In this way a loose slide cannot foul the grinding wheel and shatter.

Mounting technique. The need for uniform thickness of the Canada balsam film between the rock slice and the slide, together with the need

to avoid brittleness in that film, call for modifications in the mounting of sections for grinding under a high-speed wheel. The following procedure has been found successful: the rock slice is placed on a balsam film on the slide, and the mount is turned over and pressure applied to the slide above the centre of the slice. This will orient the slice parallel to the slide surface. With practice a similar pressure applied to a series of slices by this method will achieve a uniform thickness in the balsam film on each of them. The strain on normally prepared Canada balsam produced by a surface-grinding wheel will usually cause it to spring from the slide, and this is overcome by giving the balsam slightly less than the normal 'cooking' when mounting. The degree of 'under-cooking' must be discovered by experience, too little 'cooking' resulting in warping and rucking of the balsam film, with damage to the thin slice. When the best conditions are realized there is neither springing nor warping, and the slice is evenly ground.

Grinding technique. As the bases of the rock slices rest on a nearly identical thickness of Canada balsam film, measurement of the progressive grinding of one slice is all that is required in grinding all seven slices. One of the slices is measured by micrometer before it is mounted on a slide. In clamping the seven slides in the chuck this 'master slice' is placed at one end, and the table is raised until the grinding wheel touches it. From this datum level grinding is continued (0·01 inch traverses have been found suitable) until the limit of machine grinding is approached. The two final traverses may be taken at 0·004 inch and 0·002 inch respectively (all these measurements being read from the scale on the height adjustment of the table). Experience suggests that the limit of machine grinding is reached when the slice is 0·006 inch thick. Machine grinding below this thickness causes damage to the slice. Final grinding by hand on fine carborundum completes the process.

Acknowledgements. I should like to acknowledge the helpful advice and criticism of the manuscript by Dr. G. F. Claringbull and Dr. G. H. Francis. My thanks are also due to Mr. E. W. Davies for advice on the chuck, and to Mr. R. T. W. Atkins for the text figures.

Dept. of Mineralogy,
British Museum (Natural History),
London, S.W. 7.

H. G. Owen

Rockbridgeite from Cornwall and Devon.

The iron phosphate, dufrenite, has been recorded from a number of localities, its first and hitherto only known British occurrence, at Wheal

Phoenix, Linkinhorne, Cornwall, having been described in 1886.[1] In a recent paper, C. Frondel[2] has confirmed as dufrenite the identity of the mineral reported from several of these localities, including Wheal Phoenix, but found that the mineral from Midvale, Rockbridge Co., Virginia, U.S.A., previously referred to as dufrenite, as well as some specimens from other localities, were, in fact, a different and distinct species which he named rockbridgeite.

Examination of some dufrenite-like minerals from the Stowe's section of Wheal Phoenix, collected recently by myself, has also confirmed that most of them are dufrenite, but two specimens have proved to be rockbridgeite. The powder patterns of the two latter are distinct from those of the dufrenite and exactly match those of rockbridgeite from the type-locality. Following this, powder photographs were taken of another, similar, dark green fibrous mineral collected by myself in 1936 at East Wheal Russell, Tavistock, Devon; this mineral also has proved to be rockbridgeite. Similar specimens of the mineral from East Wheal Russell had been collected there some time ago by Sir Arthur Russell, who had taken them for what was then all known as dufrenite; I have examined these specimens and have no doubt that they are also rockbridgeite.

These appear to be the first known occurrences of rockbridgeite in the British Isles.

Dept. of Mineralogy,
University of Oxford.

ARTHUR W. G. KINGSBURY

[1] E. Kinch and F. H. Butler, Min. Mag., 1886, vol. 7, p. 65; E. Kinch, ibid., 1888, vol. 8, p. 112.

[2] Amer. Min., 1949, vol. 34, p. 513.

PROCEEDINGS
OF THE
MINERALOGICAL SOCIETY
(1956)

EXCERPT MINUTES OF COUNCIL MEETING

Held in the Apartments of the Geological Society, Burlington House, London W., 26 January 1956, at 3 p.m.

Prof. L. Hawkes, President, in the Chair.

The following were provisionally elected Ordinary Members of the Society: Keith John Ackermann, Nicolas Aguilera-Herrera, Douglas Colin Davidson, Colin Stewart Exley, Anthony Marshall Freke, Raymond Edmond Galopin, Charles James Hughes, Solomon Kaiman, Heinrich Martin Köster, Robert Douglas Mackay, Leonard Gene Schultz, Kenneth Harold Wheatley, and John Frederick George Wilkinson.

The deaths of Dr. Edmondson Spencer, Dr. George Davenport Osborne, and Col. Nicolas Timothy Belaiew were reported.

The resignations of Mr. J. G. C. Leech, Dr. A. M. B. Douglas, Mr. R. J. Davies, Mr. C. A. Fothergill, Mr. E. W. Taylor, and Mr. A. W. Scoble were accepted.

Reports were received from the Treasurer and the Editors, and from the Clay Minerals Group.

The revised constitution adopted at the Annual General Meeting of the Clay Minerals Group (see below, pp. lxv–lxviii) was approved.

SPECIAL GENERAL MEETING

Held in the Apartments of the Geological Society, Burlington House, London W., 26 January 1956, at 5 p.m.

Prof. L. Hawkes, President, in the Chair.

Forty-three Members were present.

Minor alterations to the Bye-laws, to make provision for more than one Editor to hold office in the Society, were adopted. These amendments are incorporated in the Bye-laws as printed on pp. x and xi of this volume.

GENERAL MEETING

Held in the Apartments of the Geological Society, Burlington House, London W., 26 January 1956, at 5.10 p.m.

Prof. L. Hawkes, President, in the Chair.

Forty-three Members and five Visitors were present.

The elections of thirteen Ordinary Members of the Society provisionally made by the Council were confirmed.

The following exhibit was shown:

A new design of holder for thin rock section grinding by means of diamond impregnated wheels: by the Department of Mineralogy, British Museum (Natural History).

The following papers were read and discussed:

1. Determination of the composition of kalsilites by an X-ray method: by Prof. Th. G. Sahama, Dr. K. J. Neuvonen, and Mr. Kai Hytönen (vol. 31, p. 200).

2. Collophane from the chalk: by Mr. G. Brown and Mr. C. D. Ollier (vol. 31, p. 339).

3. The structures of the plagioclase felspars. VII. The heat treatment of intermediate plagioclases: by Dr. P. Gay and Dr. M. G. Bown (vol. 31, p. 306).

4. Replacements involving early carnallite in the potassium-bearing evaporites of Yorkshire: by Dr. F. H. Stewart (vol. 31, p. 127).

5. The Eskdalemuir tholeiite and its contribution to an understanding of tholeiite genesis: by Dr. R. B. Elliott (vol. 31, p. 245).

The following papers were taken as read:

1. A phase-contrast microscopic study of the surface structure of blende crystals: by Dr. A. R. Verma (communicated by the General Secretary) (vol. 31, p. 136).

2. Subsolidus data for the join Ca_2SiO_4–$CaMgSiO_4$ and the stability of merwinite: by Mrs. Della M. Roy (communicated by Dr. M. H. Hey) (vol. 31, p. 187).

3. Staurolite twinning: by Dr. V. J. Hurst, Prof. J. D. H. Donnay and Dr. G. Donnay (vol. 31, p. 145).

EXCERPT MINUTES OF COUNCIL MEETING

Held in the Apartments of the Royal Entomological Society, 41 Queen's Gate, London S.W. 7, 22 March 1956, at 3 p.m.

Prof. L. Hawkes, President, in the Chair.

The following were provisionally elected Ordinary Members of the Society: Wolf von Engelhardt, Robert Alexander van Nordstrand, Stanley Leonard Toyn.

The deaths of Rev. Mark Fletcher, Dr. Arthur William Groves, Prof. Heinrich Ferdinand Huttenlocher, and Prof. Duncan Leitch were reported.

The resignations of Miss K. R. Farquharson, Dr. T. N. Jewitt, and Mr. W. P. Simmons were accepted.

Reports were received from the Treasurer and the Editors, and from the Clay Minerals Group. The Treasurer presented the audited accounts for 1955, which were approved (vol. 31, pp. xlvi–xlix).

The Society's great indebtedness and thanks to Dr. L. J. Spencer for his inestimable service as Editor of the Mineralogical Magazine for 55 years was voted to be recorded.

Nominations for election to the Council were considered. The following were due to retire: Vice-Presidents, Dr. F. A. Bannister and Dr. F. Dixey; Ordinary Members of Council, Mr. T. Deans, Prof. K. C. Dunham, Mr. L. A. A. Thomas, and Dr. M. K. Wells. In view of Dr. L. H. Ahrens's impending resignation and Dr. Hey's transfer to office of editor, it was agreed to retain Mr. L. A. A. Thomas and Dr. M. K. Wells as Ordinary Members of Council. The following were proposed for election at the Anniversary Meeting in November 1956: Vice-Presidents, Prof. L. R. Wager and Dr. A. K. Wells; Ordinary Members of Council, Mr. A. Stuart, Dr. A. F. Seager, Prof. D. Williams, and Dr. W. H. Taylor.

GENERAL MEETING

Held in the Apartments of the Royal Entomological Society, 41 Queen's Gate, London S.W. 7, 22 March 1956, at 5 p.m.

Prof. L. Hawkes, President, in the Chair.

Thirty-five Members and five Visitors were present.

The elections of three Ordinary Members of the Society provisionally made by the Council were confirmed.

The following papers were read and discussed:

1. The quaternary section $CaSiO_3$–$MgSiO_3$–Al_2O_3: by Dr. E. R. Segnit (read by Dr. I. Muir) (vol. 31, p. 255).

2. A contribution to the mineralogy of chloritoid: by Mr. N. J. Snelling (communicated by Prof. W. A. Deer) (vol. 31, p. 469).

3. The habit of pyrite in some sedimentary rocks: by Dr. F. Smithson, with X-ray identifications by Mr. G. Brown (vol. 31, p. 314).

4. Studies in the mineralogy of the Sokumvatn region. 1. The origin, metamorphism, and metasomatism of the Bråtfjell dolomitic group: by Mr. K. J. Ackermann.

5. Manganese silicate minerals from Chikla, Bhandara District, India: by Mr. S. A. Bilgrami (vol. 31, p. 326).

The following paper was taken as read:

Synthesis of spurrite and the reaction wollastonite + calcite = spurrite + carbon dioxide: by Dr. O. F. Tuttle and Dr. R. I. Harker.

EXCERPT MINUTES OF COUNCIL MEETING

Held in the Apartments of the Geological Society, Burlington House, London W., 7 June 1956, *at* 3.15 *p.m.*

Prof. L. Hawkes, President, in the Chair.

The following were provisionally elected Ordinary Members of the Society: Jürg Walter Meyer, William Richard Morgan, Ivar Werner Oftedal, Yoshihiko Shimazaki, Robert Leland Smith.

The resignation of Mr. T. Eastwood was accepted.

The names of Mr. D. B. Grigsby and Dr. R. W. Grimshaw were removed from the list of members for non-payment of subscriptions.

Reports were received from the Treasurer and the Editors, the Editorial Committee on Mineralogical Abstracts, and the Clay Minerals Group.

The Council agreed, in view of available accommodation, to all the Society's publications being sold from the office; and authorized the securing of additional paid and honorary staff to deal with the sales arrangements.

Dr. M. H. Hey was nominated by the Council as delegate to the International Geological Congress in Mexico, to be held from 4 to 11 September 1956.

The Society's appreciation and thanks were conveyed to Sir Arthur and Lady Russell for their hospitality at a Garden Party at Swallowfield Park on 2 June.

GENERAL MEETING

Held in the Apartments of the Geological Society, Burlington House, London W., 7 June 1956, *at* 5 *p.m.*

Prof. L. Hawkes, President, in the Chair.

Forty-three Members and four Visitors were present.

The elections of five Ordinary Members of the Society provisionally made by the Council were confirmed.

The following exhibit was shown:

A furnace for the study of ordered, irreversible, thermal transitions using a Weissenberg X-ray camera: by Miss L. S. Dent.

The following papers were read and discussed:

1. Kingite, a new hydrated aluminium phosphate from Robertstown, South Australia: by Dr. K. Norrish, Miss L. E. R. Rogers, and Mr. R. E. Shapter (vol. 31, p. 351).

2. Arsenopalladinite (Pd_3As), a new mineral from Itabira, Brazil: by Dr. G. F. Claringbull and Dr. M. H. Hey.

3. The composition and structure of botallackite from Cligga Head, Cornwall: by Mr. P. G. Embrey (with a note on the occurrence by Mr. A. W. G. Kingsbury).

4. A further examination of tobermorite from Loch Eynort, Scotland: by Mr. J. A. Gard and Dr. H. F. W. Taylor (vol. 31, p. 361).

5. Birnessite, a new manganese oxide mineral from Aberdeenshire, Scotland: by Dr. L. H. P. Jones and Dr. A. A. Milne (vol. 31, p. 283).

The following papers were taken as read:

1. An effect of depth of focus on micrometric analysis: by Dr. R. B. Elliott (vol. 31, p. 272).

2. The Holmes effect and the lower limit of modal analysis: by Dr. F. Chayes (vol. 31, p. 276).

EXCERPT MINUTES OF COUNCIL MEETING

Held in the Apartments of the Geological Society, Burlington House, London W., 1 November 1956, *at* 3 *p.m.*

Prof. L. Hawkes, President, in the Chair.

The following were provisionally elected Ordinary Members of the Society: Anthony William Allen, Jose Luis Amoros, Sturges Williams Bailey, Lesley Scott Dent, Manuel Font-Altaba, Rui Ribeiro Franco, Arthur Orpen Fuller, Liselotte Heller, Gerhard William Leo, Frank Hall Skelding, Eugen Stumpfl, Alan Herbert Weir.

The deaths of Mr. T. C. F. Hall, Dr. H. S. Simons, Dr. N. L. Bowen, Dr. A. E. J. Vickers, and Mr. M. Wyatt were reported.

Reports were received from the Treasurer and the Editors, the Editorial Committee on Mineralogical Abstracts, and the Clay Minerals Group.

The appointments of Dr. A. F. Seager as Honorary Publications Manager, and Miss M. S. Stapleton as Publications Clerk, to deal with the sales of the Society's publications, were reported.

The Council approved the report that advertising in the 'Mineralogical Magazine' would in future be dealt with from the Society's office.

On his retirement as Secretary of the Clay Minerals Group, the Council expressed their thanks to Dr. R. C. Mackenzie for the services he had rendered to the Group.

Mr. C. S. Brown and Dr. M. K. Wells were appointed auditors of the Society's accounts for the year ending 31 December 1956.

The Secretary read the draft of the Annual Report of the Council for the past year, and, with minor alterations, this was approved for presentation at the ensuing Anniversary Meeting.

GENERAL (ANNIVERSARY) MEETING

Held in the Apartments of the Geological Society, Burlington House, London W., 1 November 1956, *at* 5 *p.m.*

Prof. L. Hawkes, President, in the Chair.

Forty-eight Members and eight Visitors were present.

The elections of twelve Ordinary Members of the Society provisionally made by the Council were confirmed.

The General Secretary read the following:

ANNUAL REPORT OF THE COUNCIL FOR 1955–56

Membership.—The total membership on 31 October 1956 was 629 against 625 on 31 October 1955. Twenty-nine new members have been elected during the year, ten members have resigned, and the names of six members have been removed on account of arrears of subscription. The Society has lost by death nine Ordinary Members. On 31 October 1956 the membership consisted of seven Honorary Members and 622 Ordinary Members, of whom 65 are Life Members: 273 members are also members of the Clay Minerals Group.

Meetings.—The total attendance at the four general meetings held during the session 1955–56 was 180 members and 21 guests, giving an average of 50 per meeting. At these meetings 19 papers have been read; 7 have been taken as read, and 4 exhibits have been shown.

At two meetings of the Clay Minerals Group, in London and in Cambridge, 32 papers were read, and the average attendance was 50. Excursions to local laboratories were arranged in connexion with each meeting.

Editorship of the 'Mineralogical Magazine'.—The Council, deeply conscious of the enormous debt owed by the Society to him, reluctantly accepted the resignation of Dr. Leonard James Spencer, C.B.E., F.R.S., from the editorship of the 'Mineralogical Magazine' from 31 December 1955. Dr. Spencer had held this office in the Society for 55 years.

Publications.—Four numbers of the 'Mineralogical Magazine' (nos. 231–234) have been issued during the year. No. 231 was the index for volume XXX in 116 pages. The Bye-laws and List of Members (39 pages), Proceedings (12 pages), 24 papers in 282 pages with 10 plates and 46 text-figures, and 305 abstracts in 104 pages were contained in the succeeding three numbers.

The Clay Minerals Group monograph on differential thermal analysis is now complete; it is expected to be published before the end of the year. Arrangements are in hand for a second edition of the monograph on X-ray identification and crystal structures of clay minerals under the editorship of Mr. G. Brown.

Financial.—The accounts for the calendar year 1955 are published in the June (1956) number of the Magazine. The excess of assets (exclusive of the Society's library and stock of publications) over liabilities at 31 December 1955 was £7429. 9*s*. 9*d*., against £6057. 5*s*. 5*d*. at the close of 1954.

During 1955 income from the General Fund exceeded expenditure by £61. 17*s*. 8*d*. The Society's investments were augmented by the purchase of £537. 10*s*. 7*d*. 4 per cent. Consolidated Stock 1957 and £506. 4*s*. 6*d*. 4 per cent. Funding Stock 1960–90.

Three numbers of the 'Mineralogical Magazine' have been issued since the beginning of 1956, two of which have cost a total of £1183. 5*s*. 4*d*. (inclusive of authors' reprints). A grant of £150 towards the cost of publication of the Magazine has been received from the Royal Society (Parliamentary Grant-in-aid for Scientific Publications).

The balances at the Society's Bankers and in the Post Office Savings Bank on 31 October 1956 were: General Fund £3428. 16*s*. 2*d*., Miers Memorial Fund £106. 18*s*. 8*d*.

General.—With the resignation of Dr. Spencer from editorship, the Council decided that it was necessary to appoint separate editors for the 'Mineralogical Magazine' and for 'Mineralogical Abstracts', and the Bye-laws of the Society were accordingly modified at the Anniversary Meeting in November 1955.

A new Constitution of the Clay Minerals Group (see pp. lxv–lxviii) was adopted at the last Annual Business Meeting, and has since been approved by the Mineralogical Society; by it the Committee of the Group is elected annually instead of being co-opted, and in general the Management of the Group is brought more into line with that of the parent Society.

On the proposal of Mr. A. Stuart, seconded by Dr. P. Gray, the adoption of the Annual Report was carried unanimously.

A vote of thanks to the Geological Society for the use of the apartments during the past session was proposed by Mr. T. Deans, seconded by Dr. M. Bown, and carried with acclamation.

[*continued on p. lxiv*

INCOME AND EXPENDITURE ACCOU

A. GENE

1955 £	Income	£ s. d.	£
	Members' subscriptions—		
	Annual subscriptions	1104 10 2	
	Entrance fees	33 0 0	
1089			1137
	Mineralogical Magazine—		
	Advertisement fees	145 5 0	
	Sales	1978 1 11	
2640			2123
	Investment revenue—		
	Interest on investments	189 14 0	
	Post Office Savings Bank Interest	66 12 6	
216			256
	Grant from Royal Society (Parliamentary Grant-in-aid for scientific publications)		550
	Clay Minerals Group—		
	Clay Minerals Bulletin:		
	Subscriptions	77 2 10	
	Sales, including authors' reprints	170 18 2	
172			248
227	Clay Minerals Monograph, sales		6
12	*Glossary of Clay Trade Names*, sales		16
£4356			£4338

B. M

18	Investment revenue	£ s. d.	£ 17
1	Sundry revenue		1
£19			£18

OCIETY

OR THE YEAR ENDED 31 DECEMBER 1956

UND

955 £	Expenditure	£ s. d.	£ s. d.
	Mineralogical Magazine—		
	Nos. 232–235:		
	Printing	1831 15 11	
	Illustrations	131 19 1	
	Authors' reprints	182 6 8	
721	Distribution	57 17 10	
			2203 19 6
	Reprinting Bye-laws and list of members		77 11 6
	Editorial Expenses:		
	Magazine editor	72 15 3	
133	Abstracts editor	159 13 7	
			232 8 10
	Meeting expenses—		
	Notices of meetings	82 11 1	
107	General expenses in connexion with meetings	27 14 0	
			110 5 1
	General expenses—		
	Office rental and house expenses	397 6 9	
	Clerical assistance	560 2 6	
	Printing and stationery	103 19 11	
	Postage and telephone	50 7 0	
350	Sundry office expenses	30 4 11	
			1142 1 1
	Miscellaneous charges— £ s. d.		
	Office furniture and equipment 115 16 9		
	Depreciation of above 57 10 9		
		173 7 6	
	Binding 34 volumes for library	44 5 0	
	Donation Wold Cottage Meteorite Monument Fund	10 0 0	
337			227 12 6
	Clay Minerals Group—		
	Clay Minerals Bulletin:		
	Printing Bulletins 14 and 15	125 12 0	
	Authors' reprints Bulletins 11–14	77 19 6	
289			203 11 6
	General expenses:		
	Meeting expenses	13 11 4	
57	Office expenses	55 9 5	
			69 0 9
62	*Balance*, being excess of income over expenditure for the year		71 17 0
356			£4338 7 9

EMORIAL FUND

		£ s. d.
	Bank charges	0 2 8
19	*Balance*, being excess of income over expenditure for the year	18 11 6
19		£18 14 2

21 *March* 1957 — C. S. Brown, M. K. Wells } Auditors — James H. Taylor, Hon. Treasurer

MINERALOGIC

BALANCE SHEET AS

A. GENER

1955 £	Liabilities	£	s.	d.	£	s
	Fund Account—					
	Balance per Balance Sheet at 31 December 1955 . .	6893	0	4		
	Add cost of furniture purchased	115	16	9		
	Add excess of income over expenditure for year ended 31 December 1956	71	17	0		
6893					7080	1
2000	Publications Fund				2477	1
	Subscriptions, &c., received in advance—					
	Members' subscriptions	89	14	6		
	Subscriptions to *Clay Minerals Bulletin* . . .	4	10	0		
73					94	
	Sundry creditors—					
	Oxford University Press for Magazine No. 235 . .	473	15	5		
	A. Walker & Son, Ltd., for Bulletin No. 15 . . .	84	12	0		
	Royal Entomological Society for house expenses . .	37	13	0		
	Editors for sundry editorial expenses	80	11	8		
672					676	1
£9638					£10329	

B. MIB

		£	s.	d.	£	s
	Fund Account—					
	Balance per Balance Sheet at 31 December 1955 . . .	536	9	5		
	Add Excess of income over expenditure for the year ended 31 December 1956	18	11	6		
536					555	
£536					£555	

CIETY

DECEMBER 1956

ND

Assets	£ s. d.	£ s. d.
Office furniture and equipment—		
Original cost	575 7 5	
Less depreciation	153 19 11	
		421 7 6
Investments (at cost or as valued at 31 December 1951):		
£2232. 9*s*. 3½ % War Stock 1952	1856 8 6	
£753. 12*s*. 11*d*. 4 % Consolidated Stock 1957	694 4 9	
£606. 4*s*. 6*d*. 4 % Funding Stock 1960–90	598 5 0	
£250 3 % Savings Bonds 1960–70	216 17 6	
£1013. 9*s*. 6*d*. 3 % Savings Bonds 1965–75	916 7 0	
£100 3 % British Transport Stock 1978–88	77 0 0	
£275 2½ % Consolidated Stock	169 2 6	
£261. 12*s*. 6*d*. 3½ % Treasury Stock 1977–80	244 8 3	
£800 4½ % British Electricity Stock 1967–69	764 4 0	
		5536 17 6
Note:—The total market value of the above investments at 31 December 1956, was £4785. 3*s*. 3*d*.		
Deposits—		
Balance with Post Office Savings Bank		2857 1 0
Subscriptions, &c., in arrears—		
Members' subscriptions and entrance fees	94 11 0	
Subscriptions to *Clay Minerals Bulletin*	11 10 0	
		106 1 0
Sundry debtors—		
Oxford University Press for sales and advertisement fees	917 17 8	
Authors for reprints from *Clay Minerals Bulletin*	39 7 0	
Purchasers of *Clay Minerals Bulletin*	28 13 10	
		985 18 6
Cash—		
Coutts & Co., London	87 10 5	
Barclays Bank, Harpenden	234 16 9	
Cambridge & District Trustee Savings Bank	63 14 10	
Cash in hand, London	20 0 0	
,, Cambridge (Abstracts Editor)	10 0 0	
,, ,, (Secretary, Clay Minerals Group)	1 17 3	
,, Harpenden (Treasurer, Clay Minerals Group)	3 19 8	
		421 18 11
		£10329 4 5

Note:—The value of the Society's library and stock of publications is not included in the above assets.

[ORIAL FUND

	£ s. d.	£ s. d.
Investments (at cost)—		
£504. 17*s*. 4*d*. 3½ % War Stock 1952		439 7 0
Note:—The total market value of the above investment at 31 December 1956 was £355. 18*s*. 7*d*.		
Cash—Coutts & Co., London		115 13 11
		£555 0 11

irch 1957. C. S. Brown, M. K. Wells } Auditors

James H. Taylor, Hon. Treasurer.

The President read the following list of Officers and Council elected for the session 1956–57 in accordance with Bye-law 20:

President. Prof. L. Hawkes, D.Sc., F.R.S.
Vice-Presidents. Prof. L. R. Wager, M.A., Sc.D., B.Sc., F.R.S.; Dr. A. K. Wells, D.Sc., F.G.S.
Treasurer. Prof. J. H. Taylor, M.A., B.Sc., Ph.D., F.G.S.
General Secretary. Dr. G. F. Claringbull, B.Sc., Ph.D., F.G.S.
Foreign Secretary. Dr. L. J. Spencer, C.B.E., M.A., Sc.D., F.R.S.
Editor of the Journal. Dr. M. H. Hey, M.A., D.Sc.
Editor of Mineralogical Abstracts. Dr. N. F. M. Henry, B.Sc., M.A., Ph.D., F.G.S.

Ordinary Members of Council

Mr. B. W. Anderson, B.Sc., F.C.S.
Mr. S. H. U. Bowie, B.Sc.
Prof. W. A. Deer, M.Sc., Ph.D., F.G.S.
Mr. J. E. T. Horne, M.A., F.G.S.
Dr. R. C. Mackenzie, B.Sc., Ph.D., A.R.I.C.
Dr. A. F. Seager, B.Sc., Ph.D., A.K.C., F.G.S.
Mr. A. Stuart, M.Sc., F.G.S., F.R.M.S.
Dr. W. H. Taylor, M.A., Ph.D., D.Sc., F.Inst.P.
Mr. L. A. A. Thomas, B.Sc., F.Inst.P.
Dr. E. A. Vincent, M.A., B.Sc., Ph.D., A.R.I.C., F.G.S.
Dr. M. K. Wells, M.Sc., Ph.D., F.G.S.
Prof. D. Williams, D.Sc., Ph.D., B.E., M.I.M.M., F.G.S.

A vote of thanks to the retiring Members of Council was proposed by Dr. J. Zussman, and seconded by Dr. P. A. Sabine.

The following exhibits were shown:

1. A point counter for the microscope, consisting of a dial counter and special traversing stage with automatic recording: by Mr. I. H. Forbes.

2. An occurrence of kasolite and pitchblende at Tyndrum, Perthshire: by Dr. R. K. Harrison.

The following papers were read and discussed:

1. Painite, a new mineral from Mogok, Burma: by Dr. G. F. Claringbull, Dr. M. H. Hey, and Mr. C. J. Payne (vol. 31, p. 420).

2. An X-ray and electron-microscope study of rhodesite: by Mr. J. A. Gard and Dr. H. F. W. Taylor.

3. An X-ray investigation of some rare-earth silicates: cerite, lessingite, beckelite, britholite, and stillwellite: by Dr. P. Gay (vol. 31, p. 455).

4. Saponite from Allt Ribhein, Fiskavaig, Skye: by Dr. R. C. Mackenzie, with electron microscope data by Mr. J. A. Gard.

The following papers were taken as read:

1. Sepiolite at a locality in the Keuper Marl of the Midlands: by Mr. P. S. Keeling (communicated by Mr. D. A. Holdridge) (vol. 31, p. 328).

2. A case of epitaxic replacement: by Prof. I. Kostov (vol. 31, p. 333).

CONSTITUTION OF CLAY MINERALS GROUP

(*Revised at the Annual General Meeting, 1956*)

Name:

1. The name of this Group shall be 'The Clay Minerals Group of the Mineralogical Society'.

Aims:

2. The aim of the Group shall be to further the study of clay minerals and allied substances:

(*a*) by facilitating the exchange of information between members of the Group, and, in general, all those interested in clay minerals;

(*b*) by providing facilities for the reading and discussion of papers on the methods and results of research on clay minerals and allied topics;

(*c*) by stimulating interest in clay mineralogy;

(*d*) by encouraging the practical applications of clay mineral research;

(*e*) by such other means as the Committee and the Group may from time to time think opportune, subject to the approval of the Council of the Society.

Membership:

3. Only members and honorary members of the Society are eligible for membership of the Group.

4. All those eligible for membership of the Group may become members, without additional payment, by written application to the Secretary of the Group.

Termination of Membership:

5. Membership of the Group may be ended by written notice to the Secretary of the Group.

6. Any member of the Group who ceases to be a member or honorary member of the Society shall therewith simultaneously cease to be a member of the Group.

Management:

7. The activities of the Group shall be managed by a Committee consisting of a Chairman, a Secretary, a Treasurer, an Editor of the Bulletin, and six Ordinary Members who shall be elected annually, together with the preceding Chairman, who shall be entitled to remain on the Committee for three years from the date of his retirement from office, and, *ex officio*, the Secretary of the Mineralogical Society. All Members of Committee must be normally resident within Great Britain during their period of office.

8. The Chairman, Secretary, Treasurer, and Editor of the Bulletin

shall be deemed the Officers of the Group, and the Chairman and Secretary shall be its official representatives in all matters pertaining to relations with the parent Society.

9. The Officers and Ordinary Members of Committee shall be elected annually at the Annual General Meeting and shall hold office from the end of that Annual General Meeting to the end of the next Annual General Meeting.

10. Two Ordinary Members of Committee shall retire annually at the Annual General Meeting, and shall not be eligible for re-election as such until the next Annual General Meeting.

11. At or before the end of June each year the Committee shall prepare a list of members nominated by the Committee as Officers and as Ordinary Members of Committee for the ensuing year, this list to be sent by the Secretary to every Member of the Group at his last known address not later than the next ensuing 31 July.

12. Additional nominations may be made by Members of the Group not being Members of Committee subject to the following conditions:

(*a*) All such nominations must be received by the Secretary not later than the next ensuing 1 September.

(*b*) Every Candidate, whether proposed as an Officer or Ordinary Member of Committee, must be proposed by no less than two Members of the Group, not being Members of the Committee, who must both sign the Candidate's Nomination Form, which must be accompanied by a statement signed by the Candidate that he accepts nomination.

(*c*) No member of the Group may propose more than two Candidates.

(*d*) No Candidate may be nominated for more than one position on the Committee.

(*e*) No Member of the Group whose name has been entered on the list of Candidates nominated by the Committee for Ordinary Membership of Committee may accept nomination under this Paragraph for any other position on the Committee.

13. If through death or for any other reason a vacancy should be created on the list circulated by the Committee, the Committee shall have the power to fill the vacancy thus created and shall notify members of this change as soon as possible.

14. If not more than ten Candidates are nominated for the positions on the Committee set out in paragraph 7, the Candidates shall be declared duly elected at the next ensuing Annual General Meeting.

15. If more Candidates are nominated for any position on the Committee than there are vacancies then an election by Ballot shall be held

16. In the event of an election by Ballot being required, the Secretary shall issue to every Member of the Group at his last-known address not later than the next ensuing 30 September a voting-paper containing the names of all Candidates duly nominated in accordance with the provisions of these Paragraphs, which list shall show the Office or other position on the Committee for which each Candidate has been nominated.

17. No vote may be cast for any Candidate whose name is not entered on the voting list, and no Member may vote for more than ten Candidates in all.

18. Every Member voting shall place his voting-paper when duly completed in an envelope, which shall be closed and placed in another envelope for return to the Scrutineers of the Ballot. The outer envelope must also be closed, must be inscribed 'Voting-Paper', and must bear the name of the Member voting, but no indication of the Voter's identity may appear on the voting-paper or on the inner envelope. Members voting may return their voting-papers enclosed in the manner prescribed to the Secretary beforehand by post or other means or may deliver them to him at the commencement of the Annual General Meeting.

19. As soon as may be convenient after the opening of the Annual General Meeting the Chairman of the Meeting shall appoint from amongst the Members present two Members, not being Members of the Committee or Candidates for election to the Committee, to act as Scrutineers of the Ballot, to whom the outer envelopes containing the voting-papers received by the Secretary shall be forthwith delivered unopened, and when this has been done the Ballot shall be declared closed.

20. Upon completion of their examination of the voting-papers the Scrutineers shall present to the Chairman of the Meeting a list showing the result of the Ballot, and if the list be in accordance with the provisions of these Paragraphs, the Chairman shall declare the new Committee to have been duly elected and to be constituted in accordance with the provisions of these Paragraphs.

21. If, however, any difficulty should arise in constituting the new Committee in conformity with the provision of these Paragraphs from the list returned by the Scrutineers owing to an equality of votes or otherwise, the decision of the Chairman, who shall have a casting vote, shall be final, provided always that in no case shall the Chairman declare elected more than eight Members who were Members of the retiring Committee.

22. The Committee shall have the power to appoint Officers, and to

co-opt Ordinary Members of the Committee to fill vacancies caused by death or resignation during the interval between two Annual General Meetings.

23. Meetings of the Committee shall be summoned by the Secretary at the order of the Chairman or of not fewer than three Members of the Committee; at such a meeting four shall be a quorum, of whom one shall be either the Chairman, the Secretary, or the Treasurer.

24. A report on the work and progress of the Group shall be submitted at each Annual General Meeting.

Meetings:

25. One Meeting of the Group (the Annual General Meeting) shall be held in each Calendar year, either in November or as near thereto as may be convenient.

26. Further meetings may be held at the discretion of the Committee. Such meetings may be either Special General Meetings (for the transaction of business affecting the constitution or management of the Group) or Ordinary Meetings.

27. Members shall be notified of the place and date of each Annual or Special General Meeting not less than three weeks in advance.

Alterations to Constitution:

28. Alterations to the Constitution may be made only with the approval of the Group (expressed by majority decision at an Annual or Special General Meeting) and of the Council of the Society; and shall not become effective until they have received such approval.

Terminology:

29. In the above text 'the Society' means the 'Mineralogical Society of Great Britain and Ireland', 'the Group' means the Clay Mineral Group of the Mineralogical Society, and 'the Committee' means the Committee of the Group, as above defined.